Nili Fossae Carbonate Plains: Solving the Carbonate Puzzle and Examining Olivine from Primitive Melts or Mantle

Land-on science to understand early aqueous environments, reservoirs of carbon, and planetary igneous evolution

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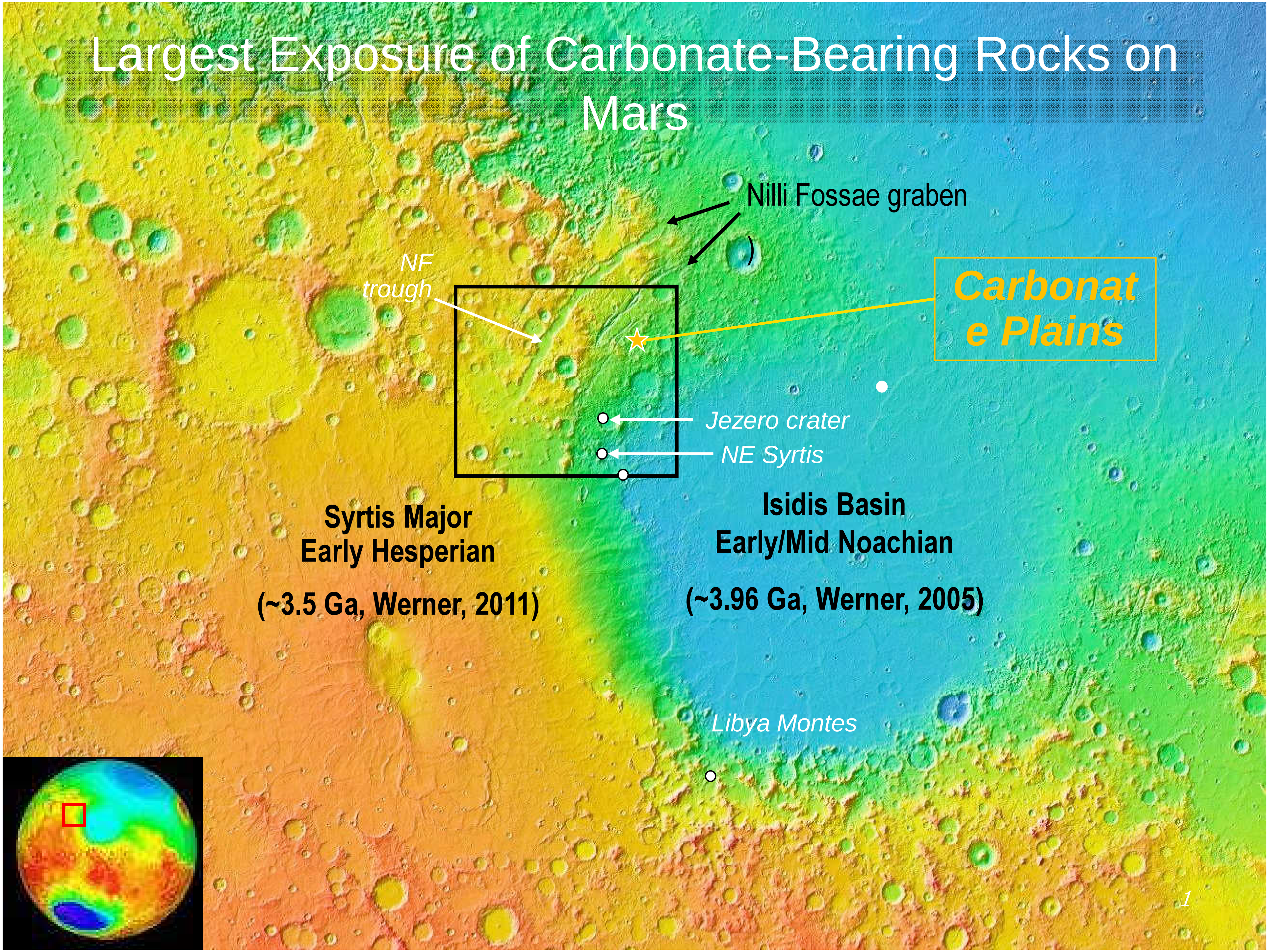
1st Mars 2020 Landing Site Workshop

May 15, 2014

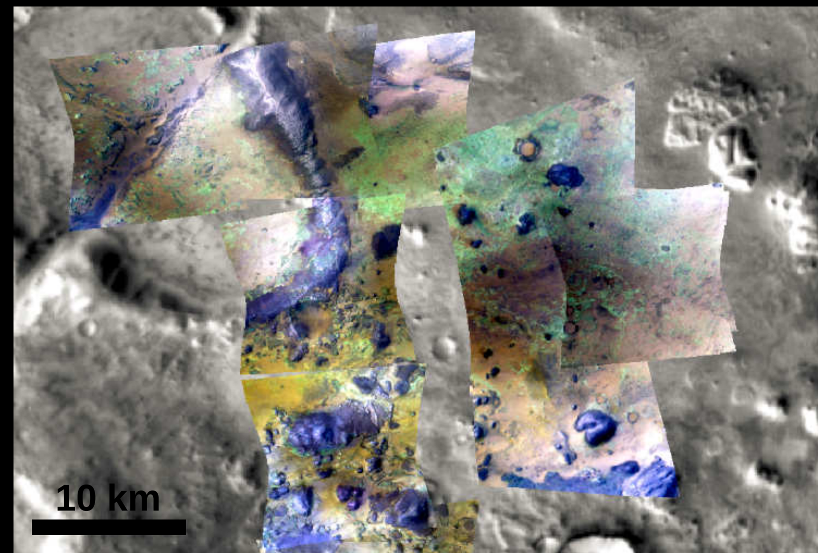
Largest Exposure of Carbonate-Bearing Rocks on Mars



Meeting Mars 2020 Science Criteria

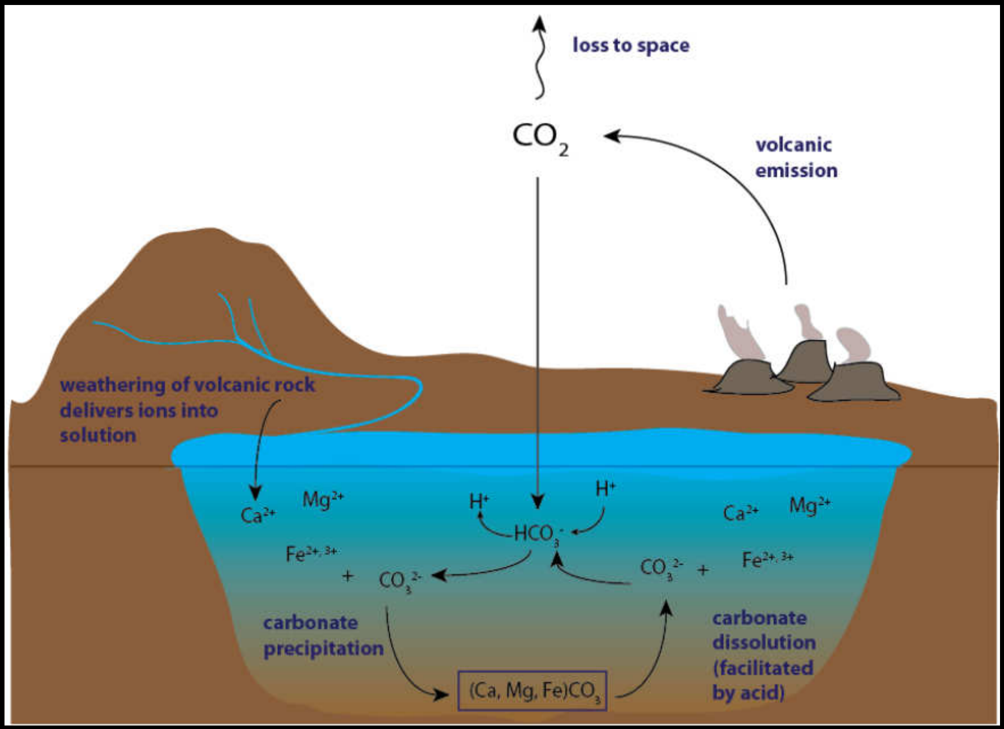
Nili Fossae Carbonate Plains geology addresses key science topics in the M2020 SDT report , E2E-iSAG sample criteria:

1. <u>Aqueous, habitable environments:</u> Largest exposure of carbonate-bearing rock on Mars, formed by precipitation from liquid water *[Ehlmann et al., 2008, Science; Niles et al., 2013, SSR]*
2. <u>Understanding Sources and Sinks of the Martian Atmosphere</u>
3. <u>Planetary Evolution & Igneous Processes</u>: Capping later mafics overly the largest olvine-rich (ultramafic?) rock unit on Mars, comprised of komatiitic lavas or impact-excavated mantle cumulates *[Hoefen et al., 1997, Science; Hamilton & Christensen, 2005, Geology; Mustard et al., SSR]*



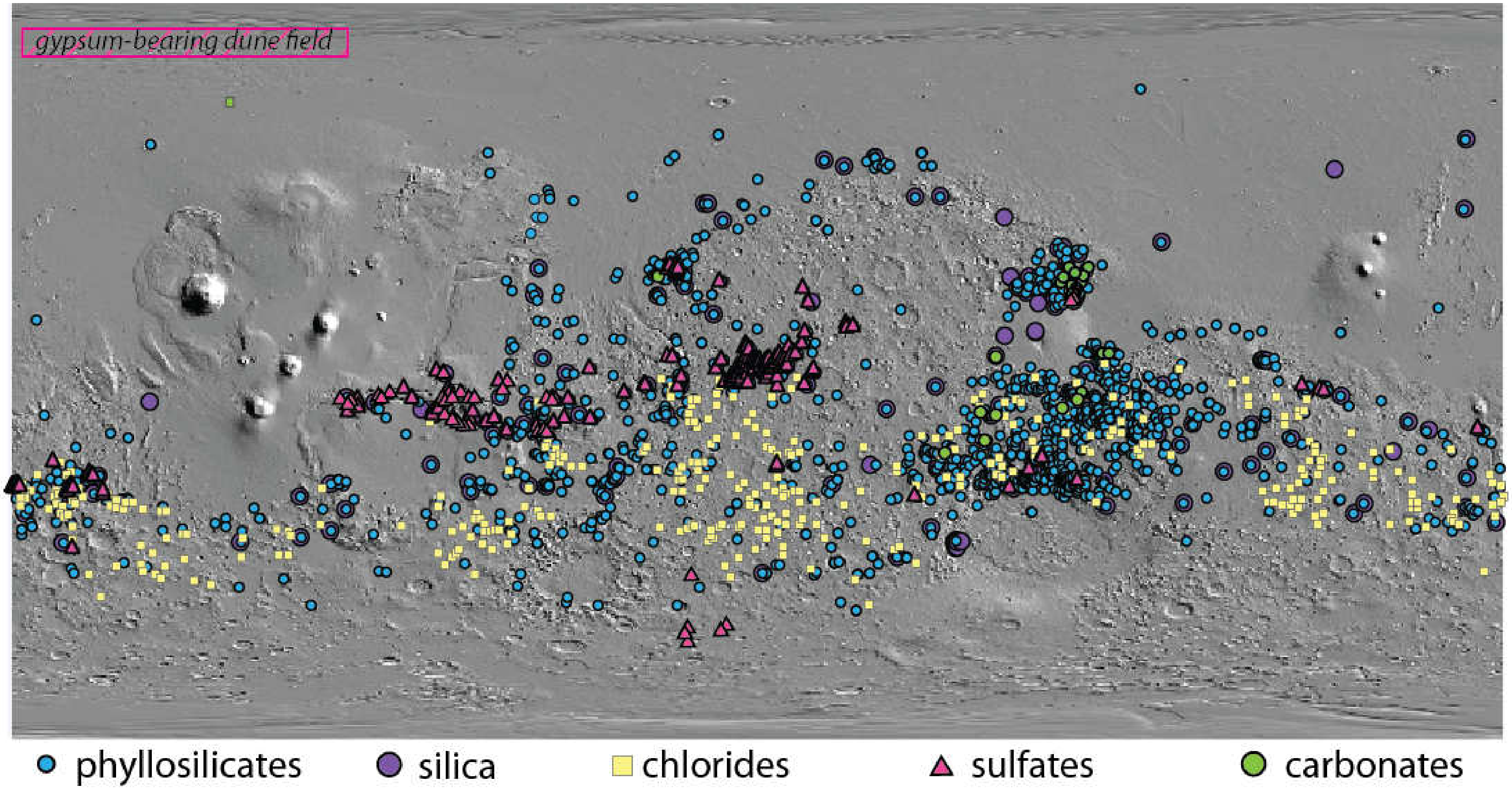
In Search of the “Missing” Martian Carbonate?

- Carbonate: a minor phase in Martian dust (<5 wt. %) [Lellouch et al., 2000; Bandfield et al., 2003] and in Martian meteorites [e.g. Bridges, 2001]
- As of 2008, not IDed in rock though expected common, weathering product with water and CO_2-atmosphere
- Implications of carbonate paucity:
  - Acidic conditions precluded carbonate formation and preservation? [Fairen et al., 2004; Bullock & Moore, 2007; Mukhin, 1996]
  - Low pCO_2 when liquid water was present at the surface? [Chevrier et al., 2007; Halevy et al., 2007]
  - Waters driving aqueous alteration on Noachian Mars were not in contact with the atmosphere? [Ehlmann et al., 2011]
  - After ~4Gyr, always low atmospheric pressure [Hu, Kass, Ehlmann, Yung, in prep]



Carbonate is rare among alteration minerals…

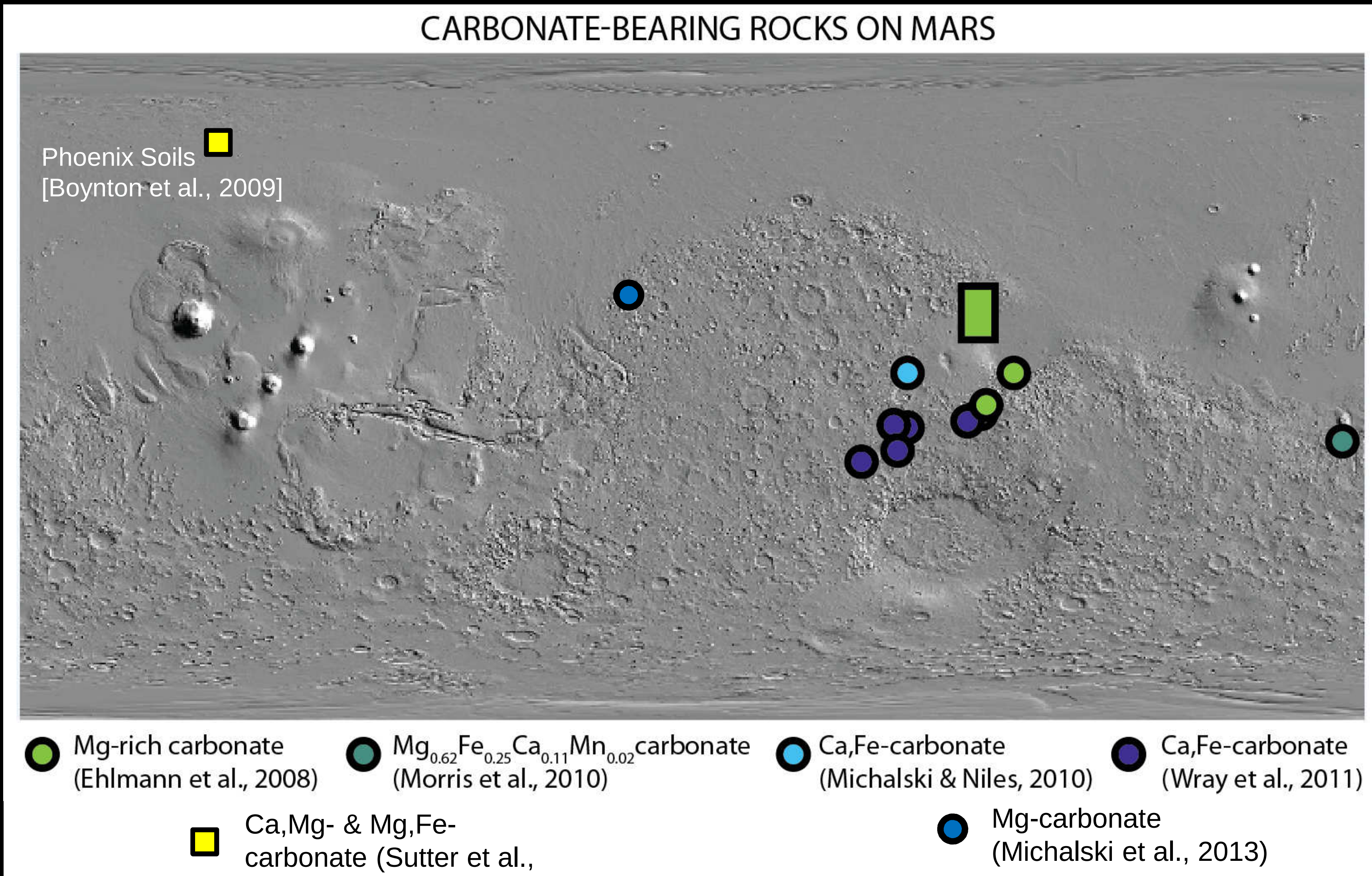
Global View of Water-formed Minerals



[Ehlmann & Edwards, in press, AREPS]

Distribution of the major classes of aqueous minerals on Mars. Phyllosilicate detections from compilations by Ehlmann et al. (2011), Carter et al. (2013), and Pan & Ehlmann (2014). Silica detections compiled by Carter et al. (2013). Chlorides compiled by Osterloo et al. (2010). Carbonate-bearing rock detections reported by Ehlmann et al. (2008) or reviewed in Niles et al. (2012) (square indicates Phoenix lander soil carbonate). Sulfate detections from Murchie et al. (2009), Milliken et al., (2010), Ackiss et al. (2012), and Carter et al., (2013), edited to remove locations with ambiguity with hydrated silicates.

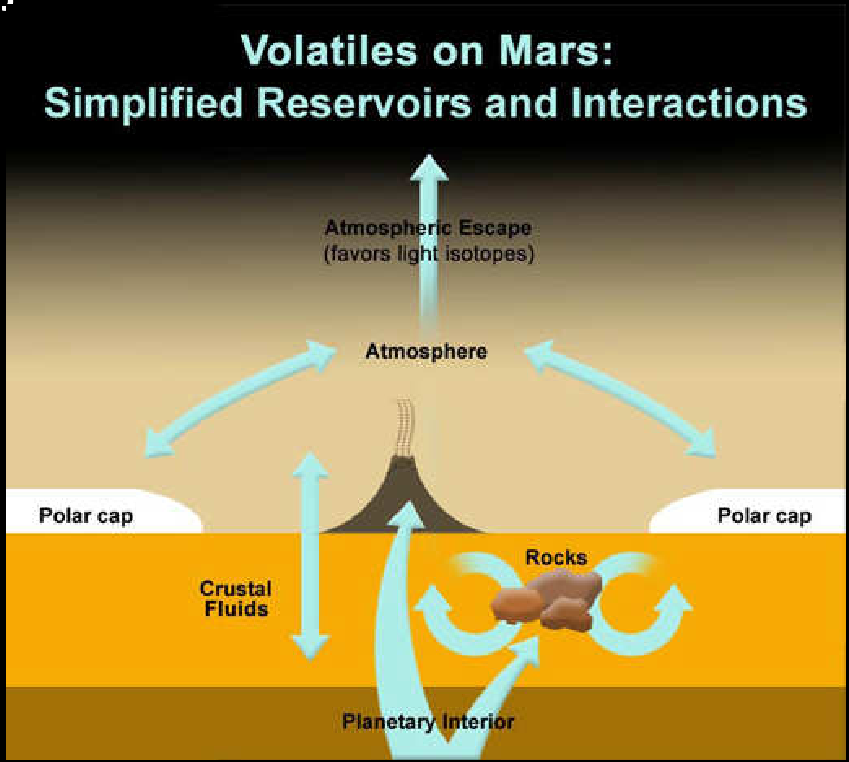
Carbonate is rare among alteration minerals…

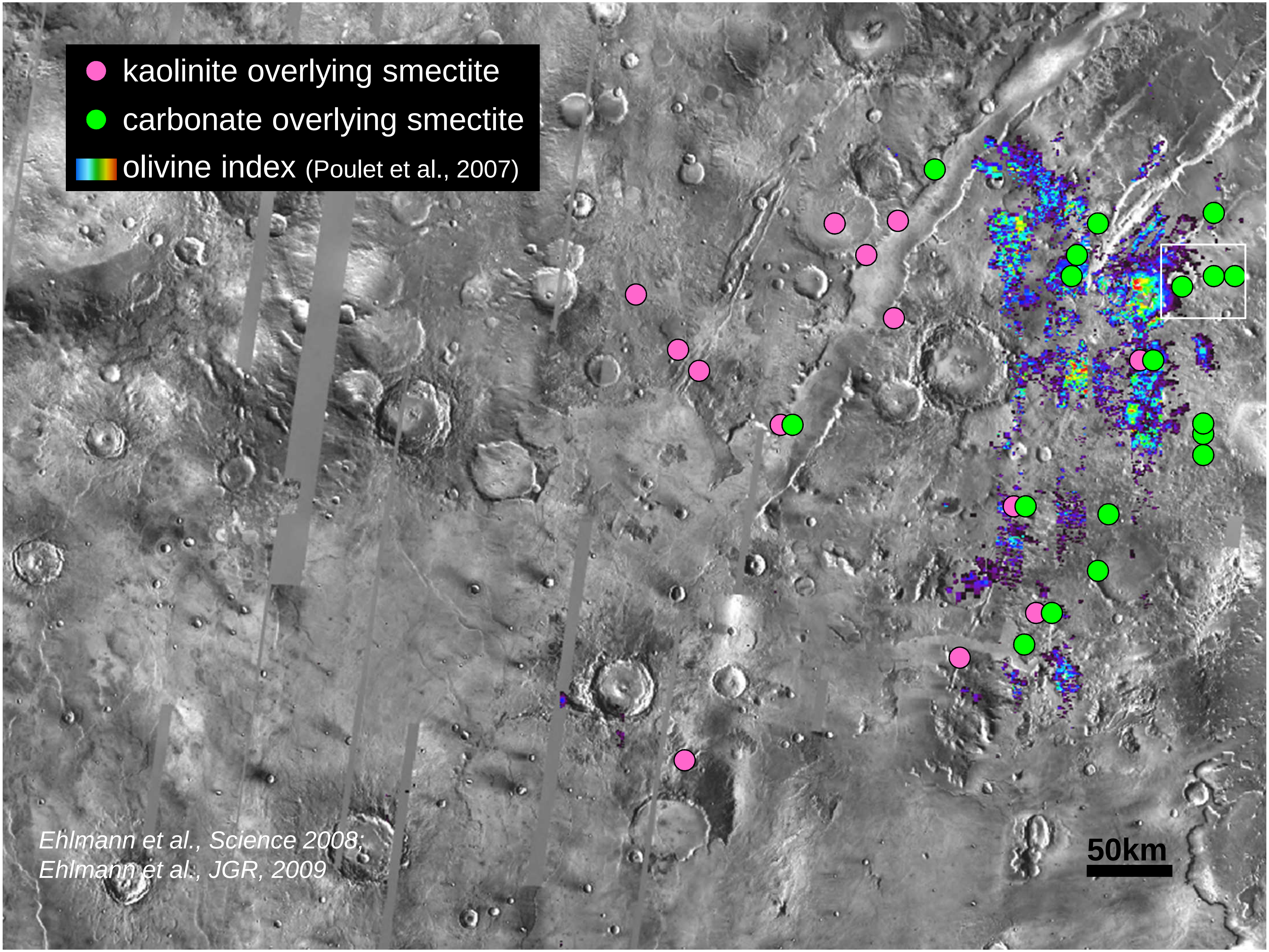


[adapted from Niles et al., 2013, SSR]

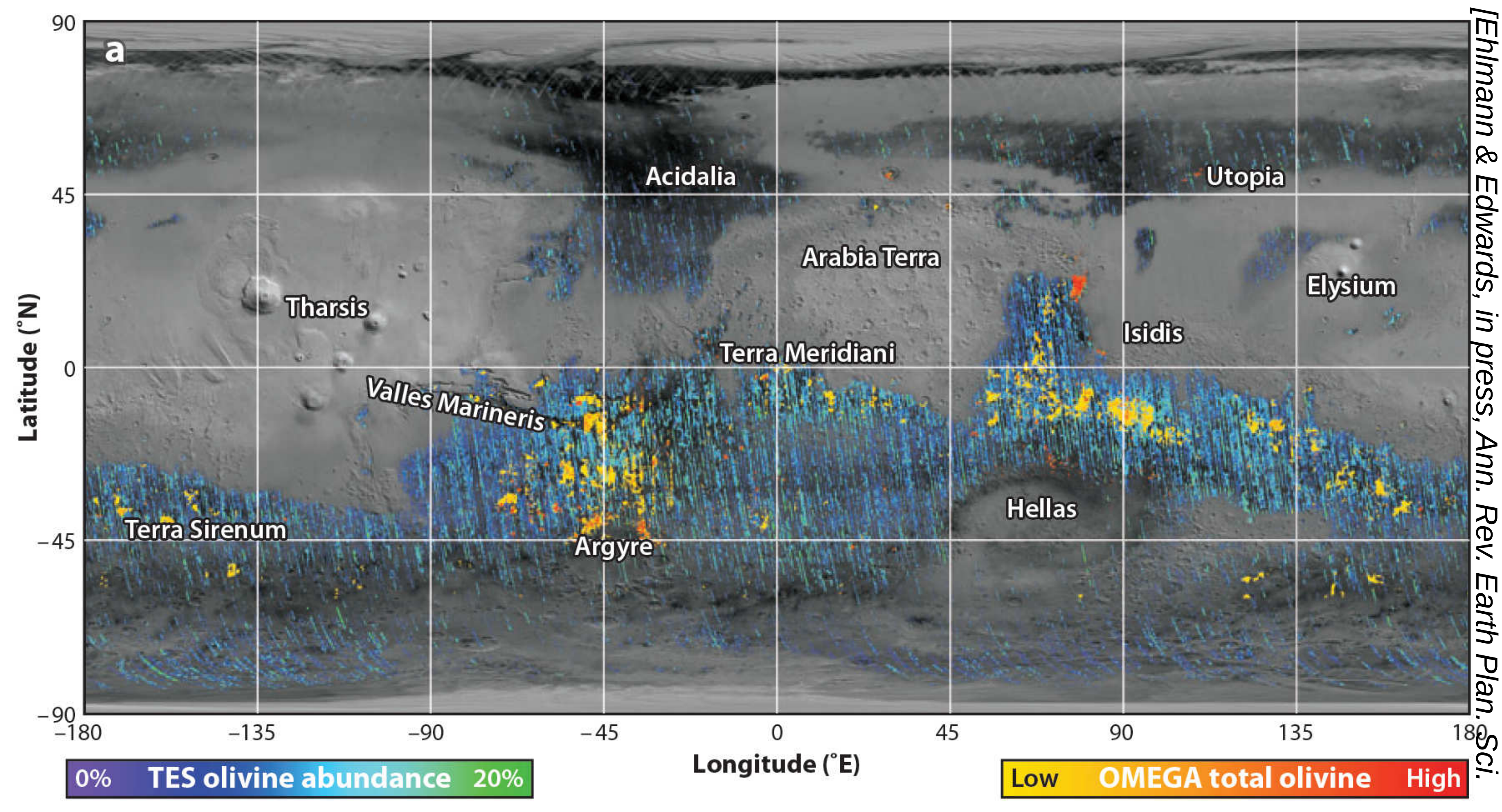
Where there is carbonate, it is special

- Some aqueous crustal environments were neutral to high pH and never experienced an overprinting acidic period
- Carbonate likely formed in conjunction with olivine weathering/ serpentinization
- Aqueous activity in Nili Fossae extended well into the Hesperian (Mangold et al., 2007, JGR)
- Carbonate persists to the present and was not removed by acid weathering
- Heart of figuring out the “case of the missing atmosphere”



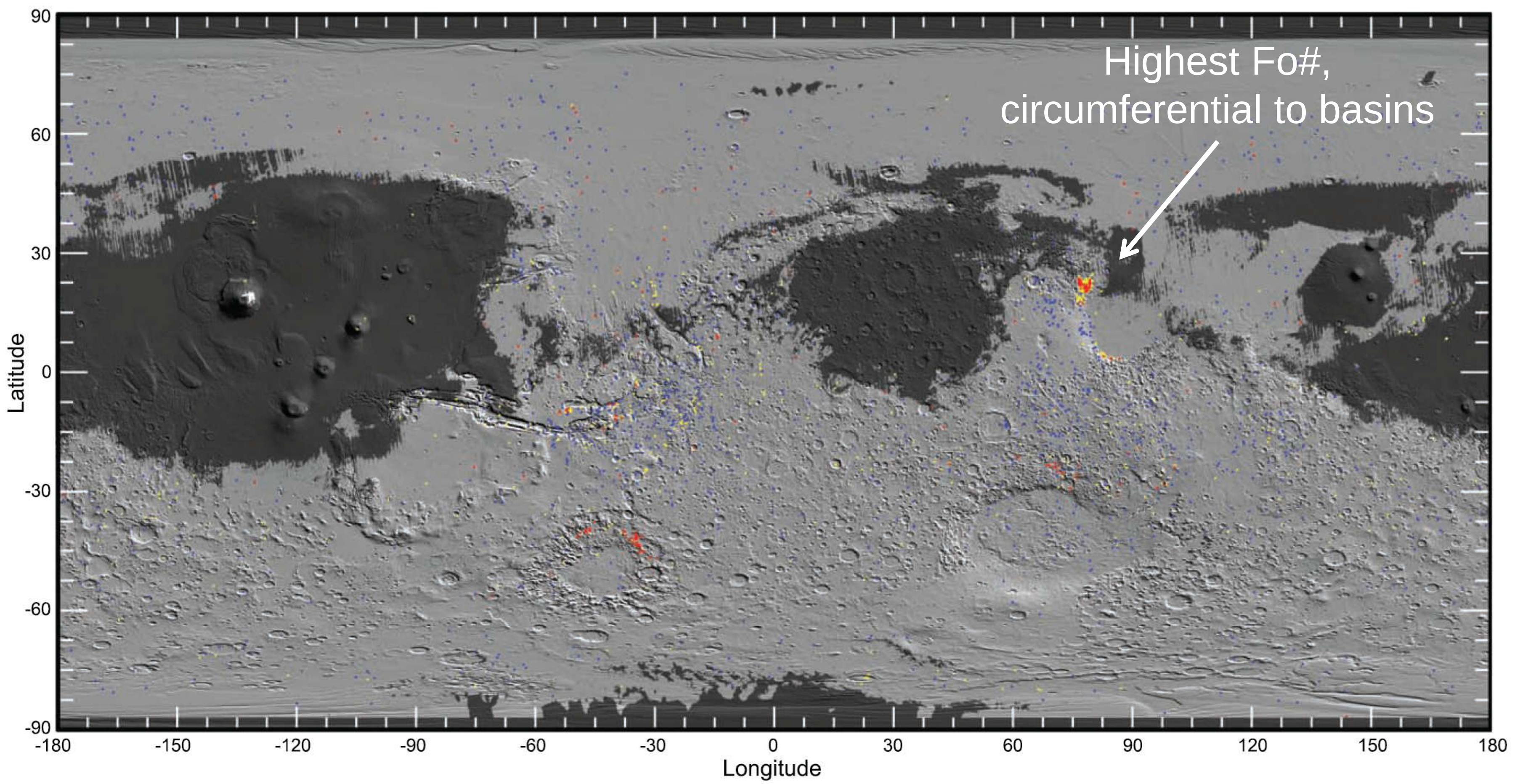

kaolinite overlying smectite
carbonate overlying smectite
olivine index (Poulet et al., 2007)
Ehlmann et al., Science 2008;
Ehlmann et al., JGR, 2009
50km

Global Olivine Abundance



[Ehlmann & Edwards, in press, Ann. Rev. Earth Plan. Sci.

High-Mg olivine from primitive melts or mantle



[Koeppen & Hamilton, 2008, JGR]

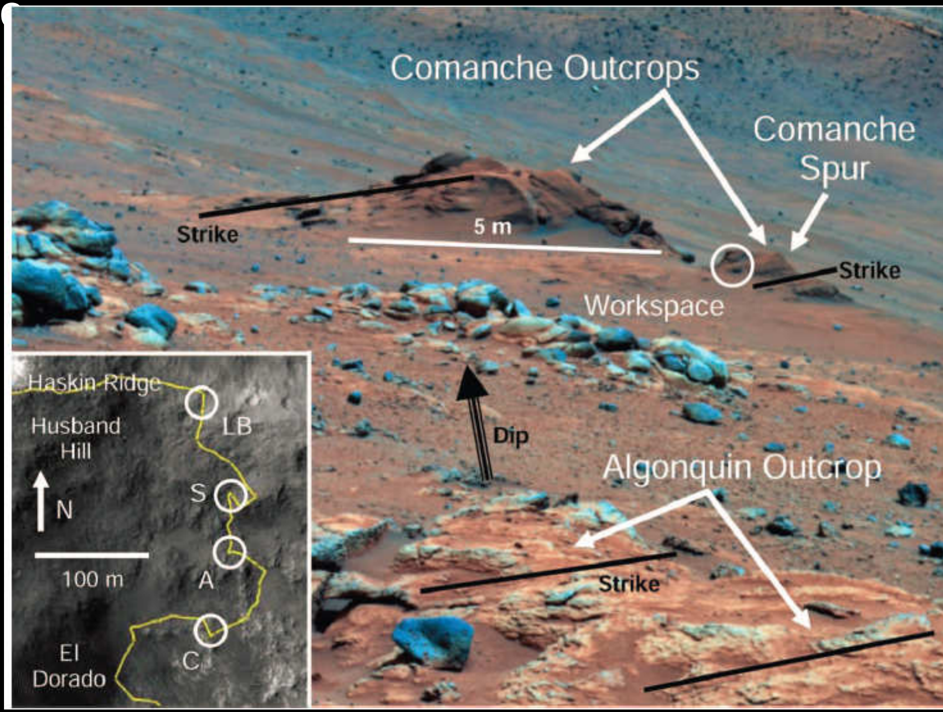
Fo75-100 Fo58-74 Fo42-57

Is this site at all typical of Mars or just “weird”?

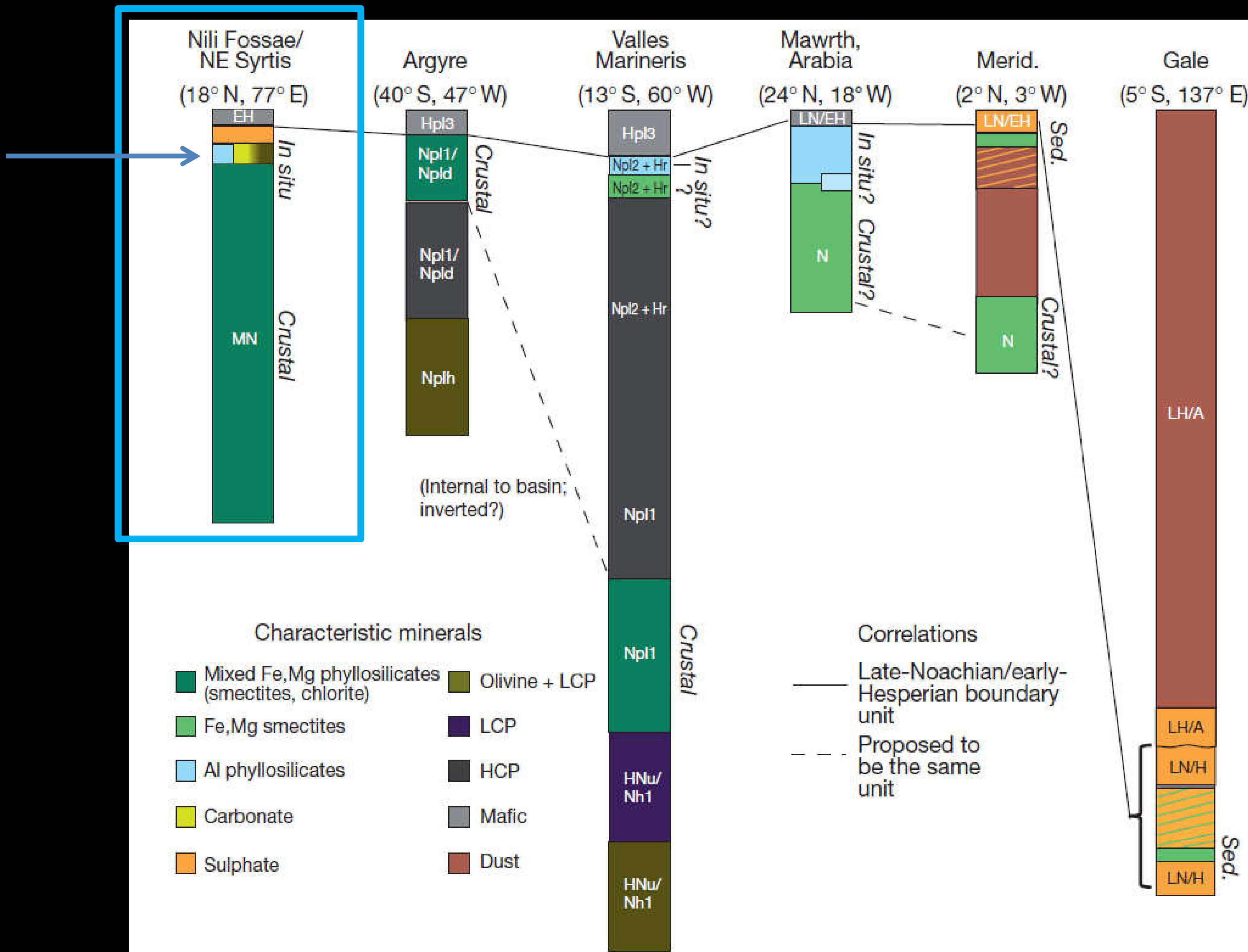
- Special because high-Mg olivine taps primitive lavas or mantle cumulates
- Other olivine/carbonate-bearing rocks like this may exist on Mars but merely be less exposed
- Mars2020 Primary mission: Special opprtunity to investigate a key habitable environment, a key process for geochemical cyling, and a unit that may tap Mars’ mantle
- Mars 2020: Extended mission: access to regionally-extensive type stratigraphy with typical alteration assemblag

<u>GUSEV CRATER:</u>
(Morris et al., 2010, Science)
40% olivine
35% amorphous silicate
25% carbonate

$(Mg_{0.62}Fe_{0.25}Ca_{0.11}Mn_{0.02})CO_3$



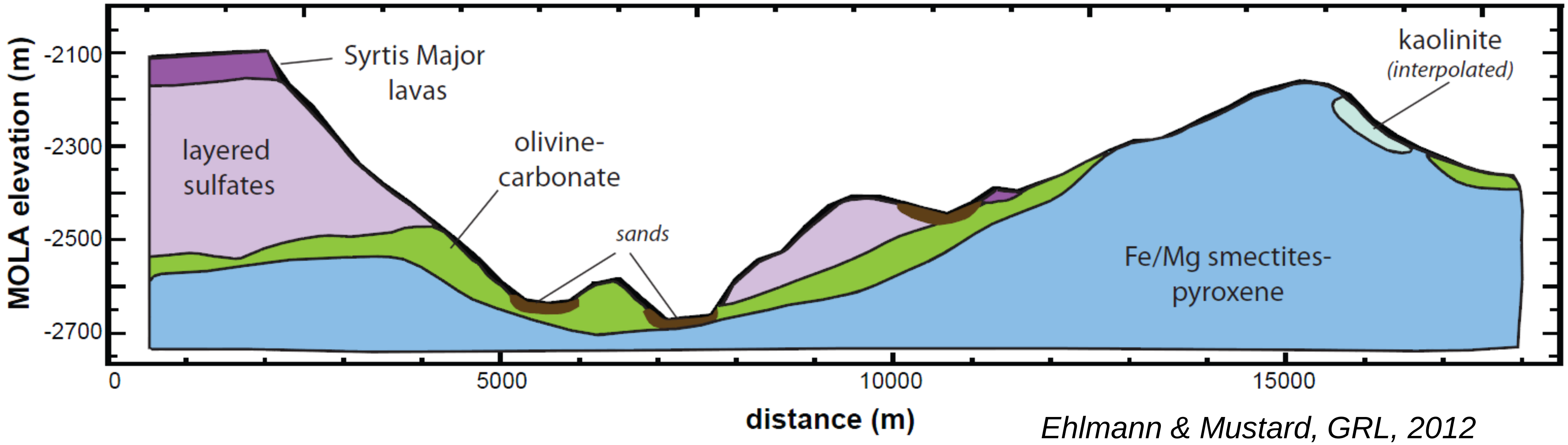
Key Martian Stratigraphies



Ehlmann, et al., 2011, Nature

Part of a Regionally Extensive, Time-Bracketed and Well-Understood Section

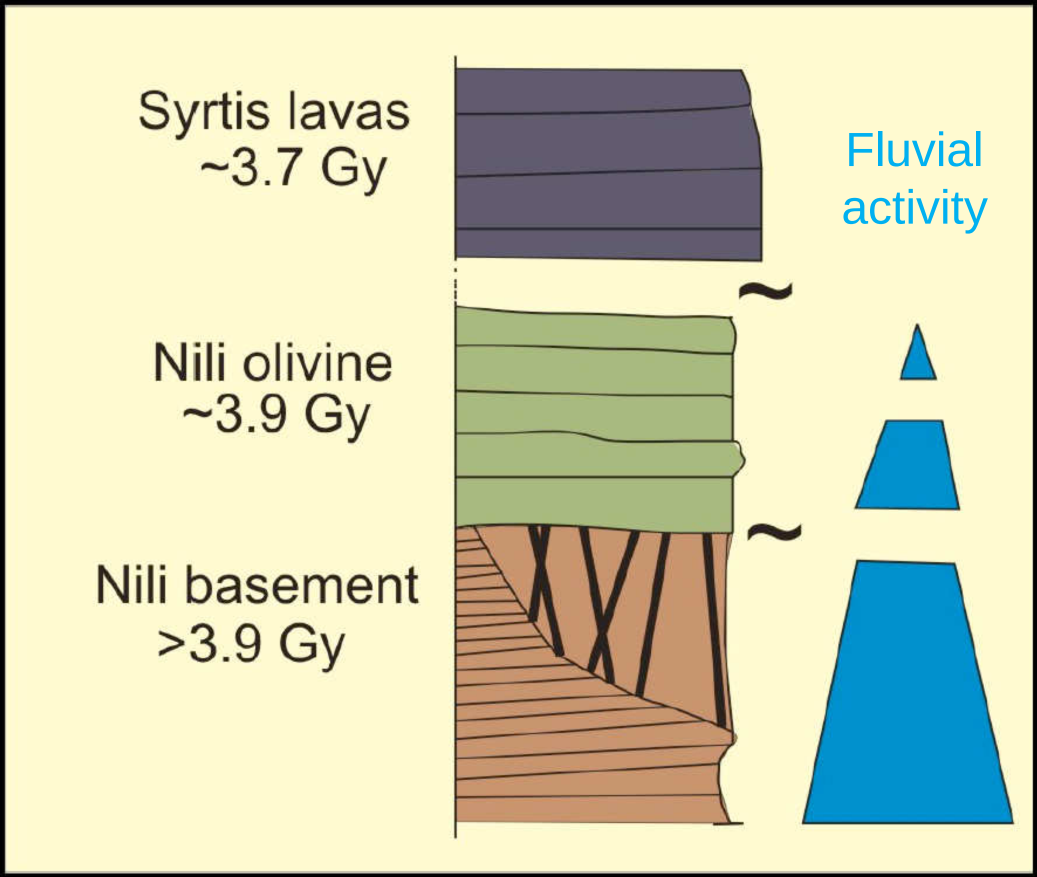
(from NE Syrtis area)



Ehlmann & Mustard, GRL, 2012

- Age Brackets:
  - Lower (oldest): Age of the Isidis impact disrupted the Fe/Mg smectite/pyroxene unit (parts are brecciated)
  - Upper (youngest): Overlying mafics, Hesperian Syrtis Major volcanic province

A Schematic History of Water



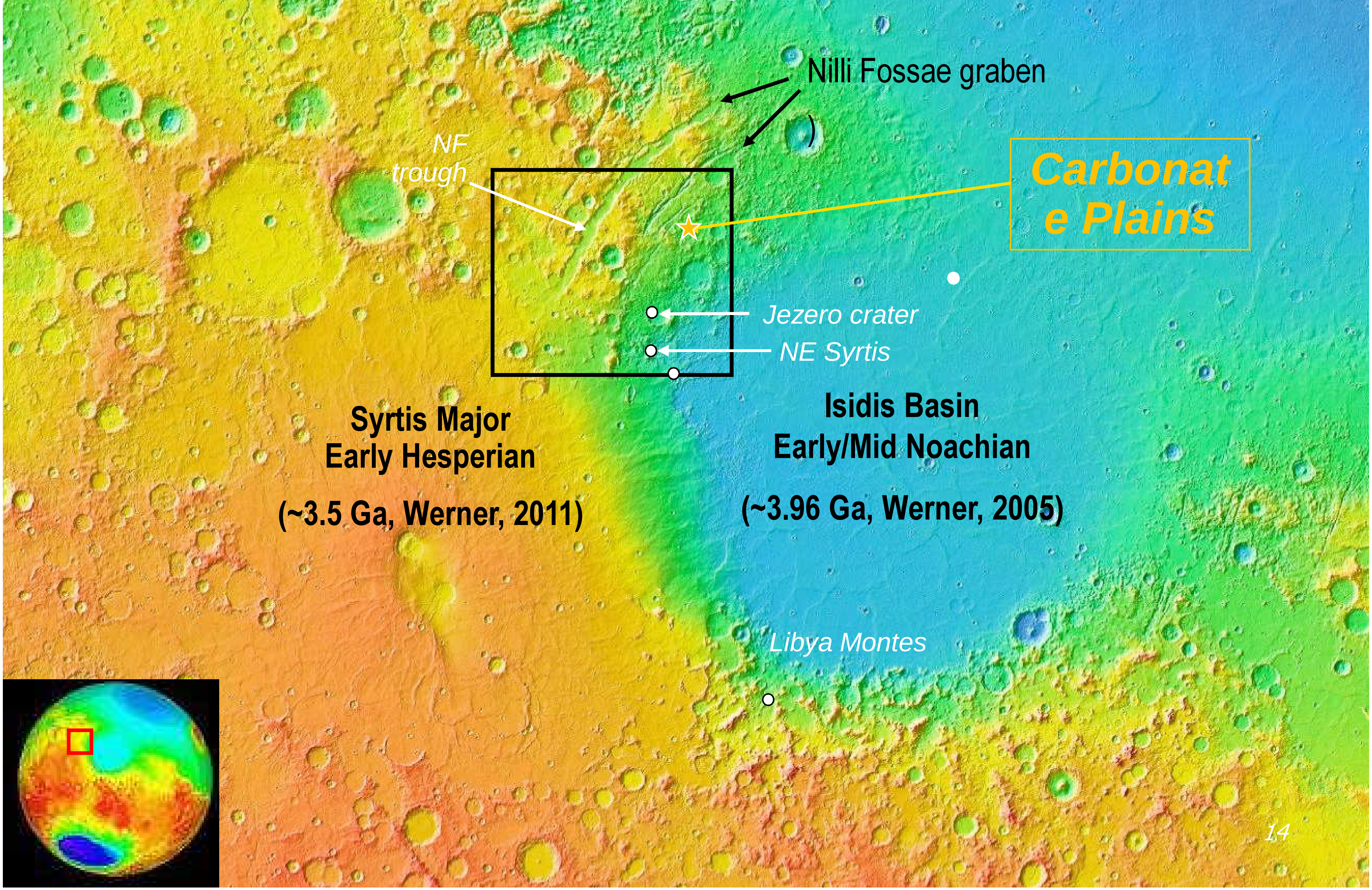
No alteration

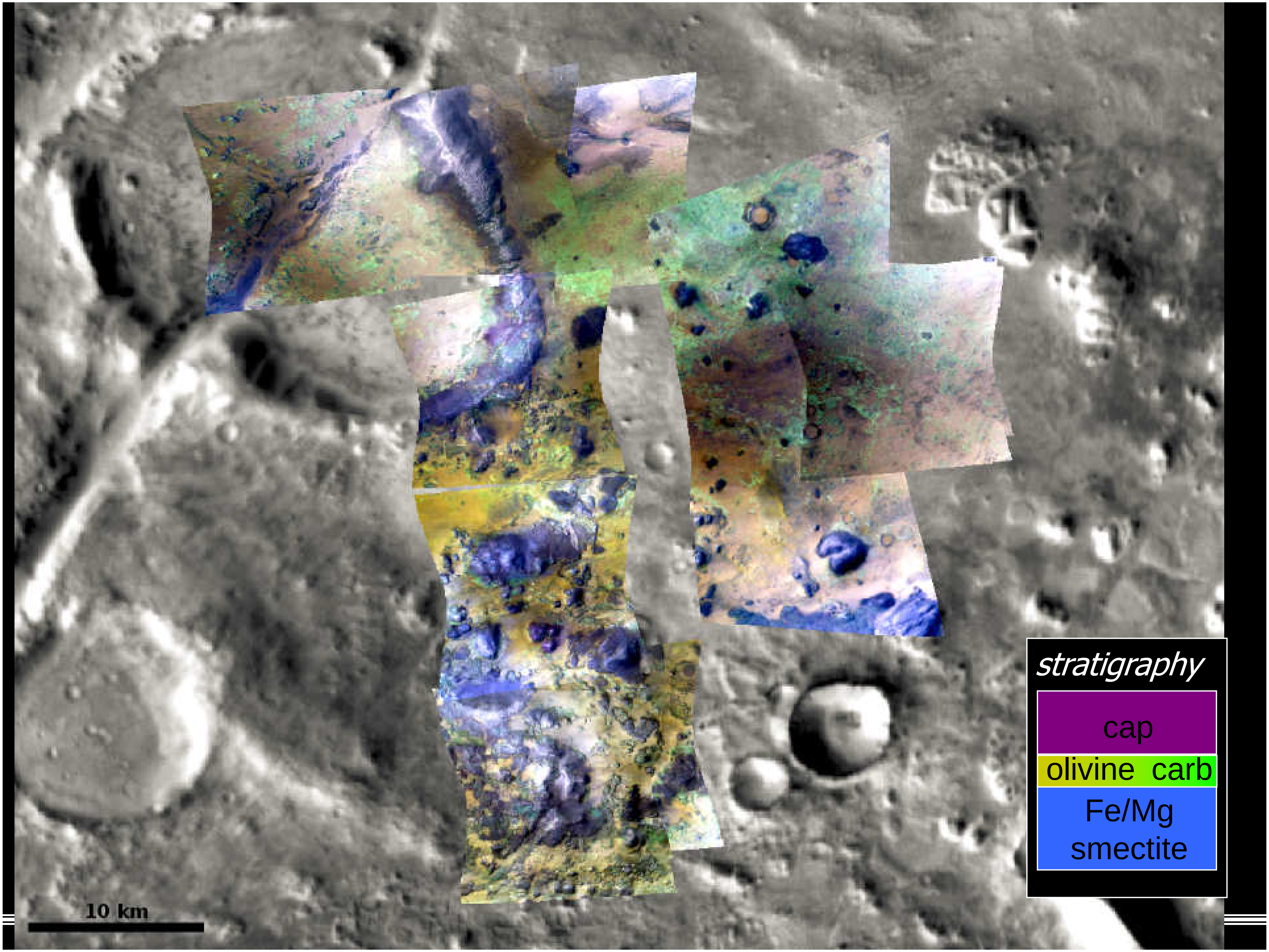
Partial /local alteration

Basement alteration

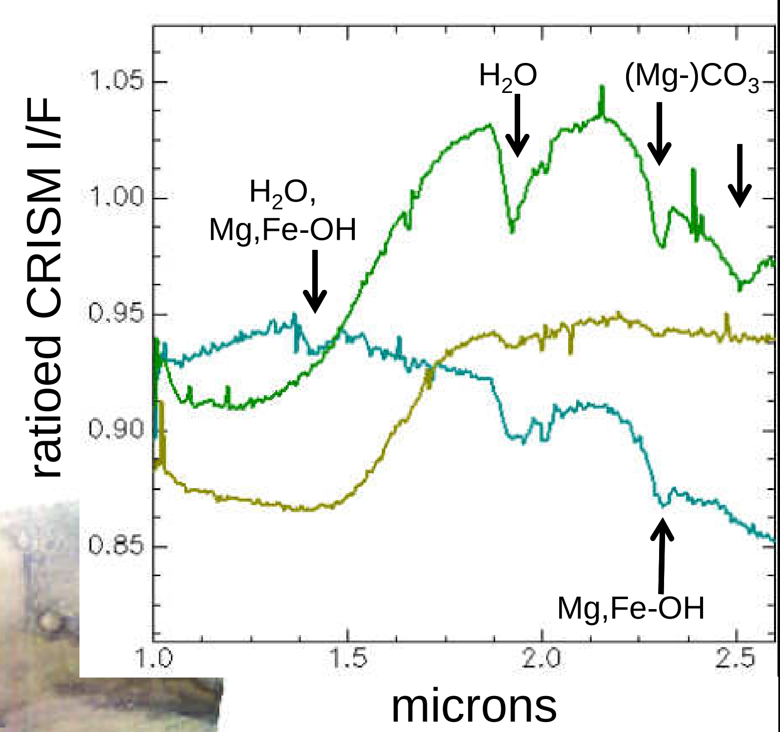
Mangold et al., 2007, JGR

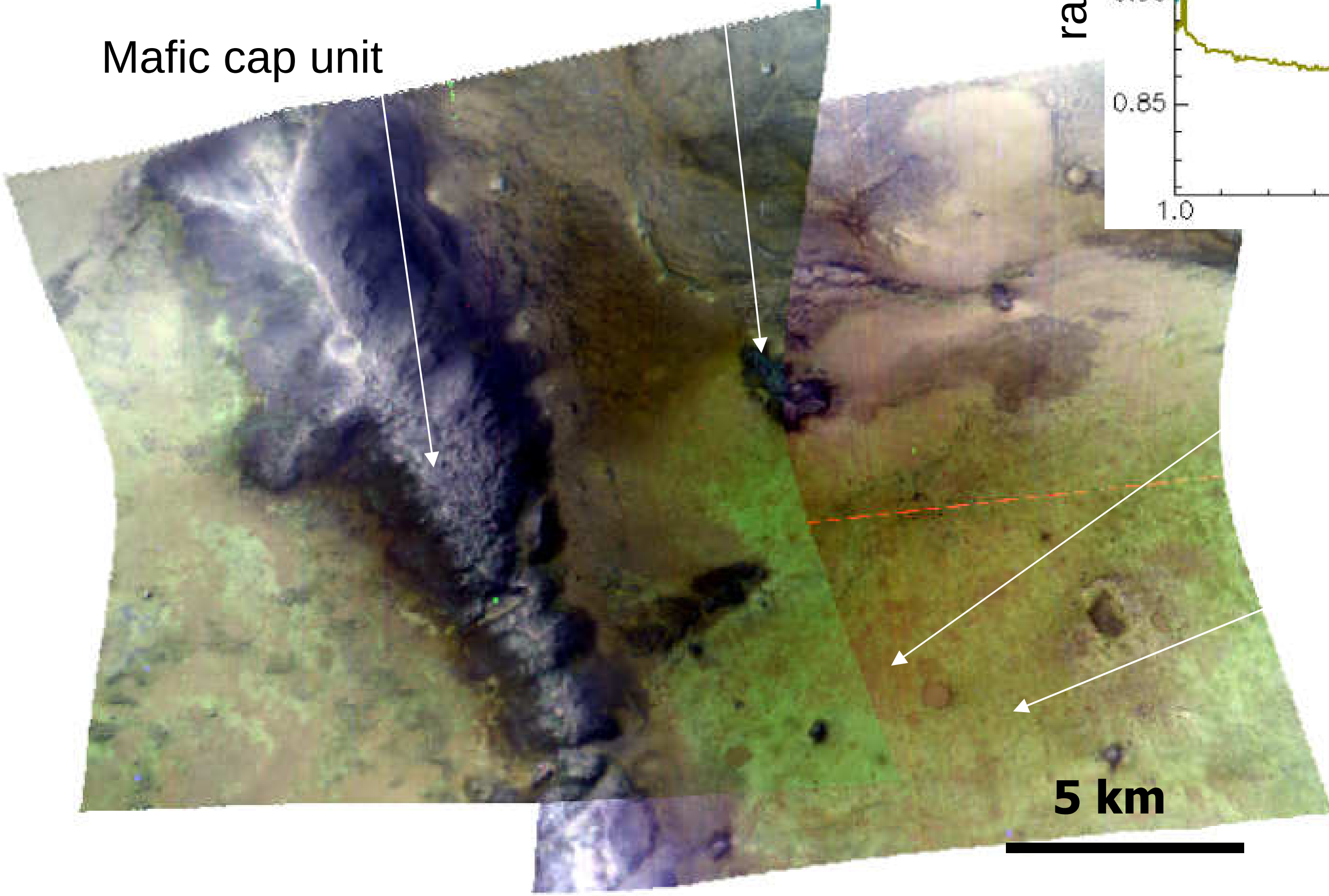
Largest Exposure of Carbonate-Bearing Rocks on Mars

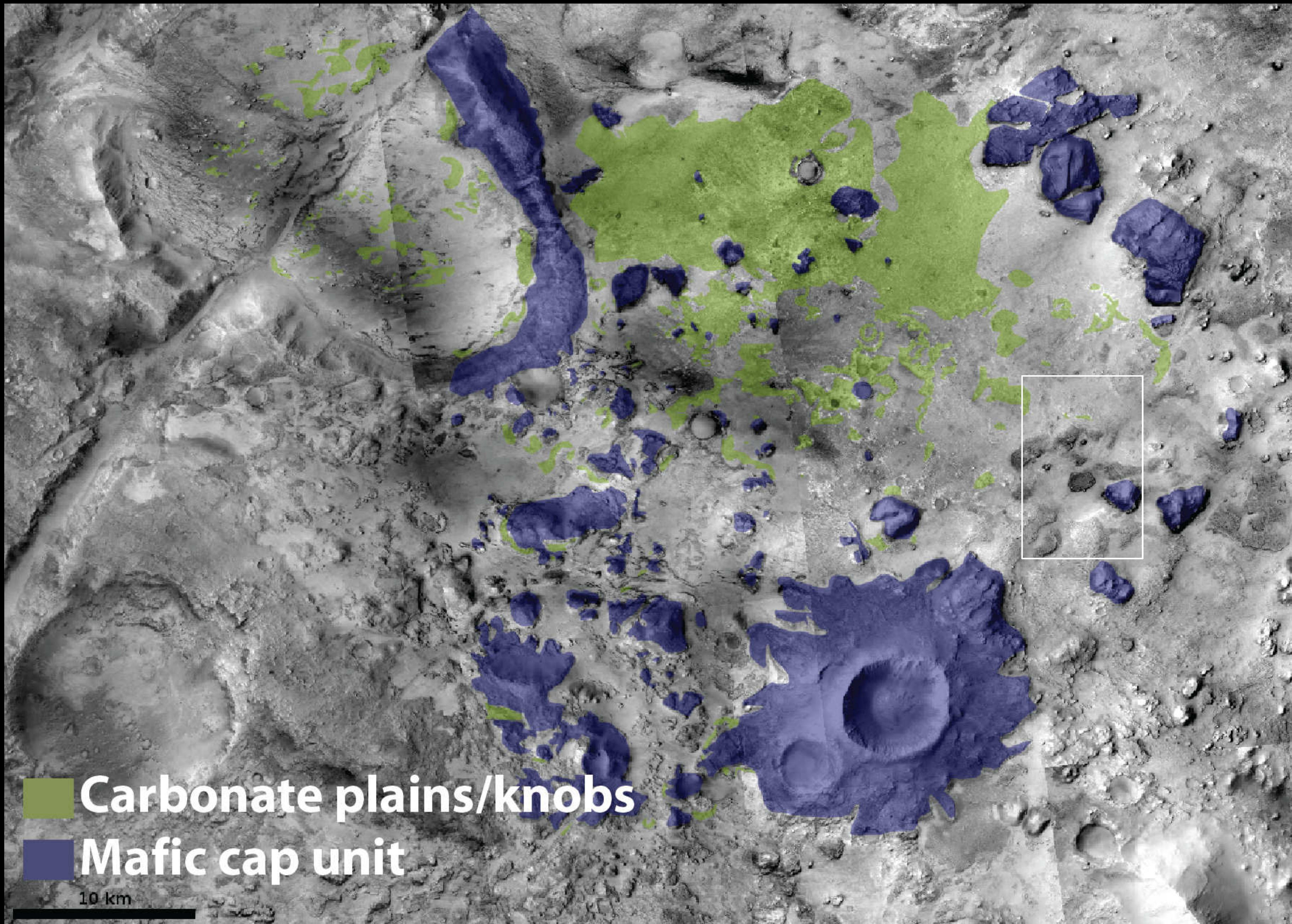


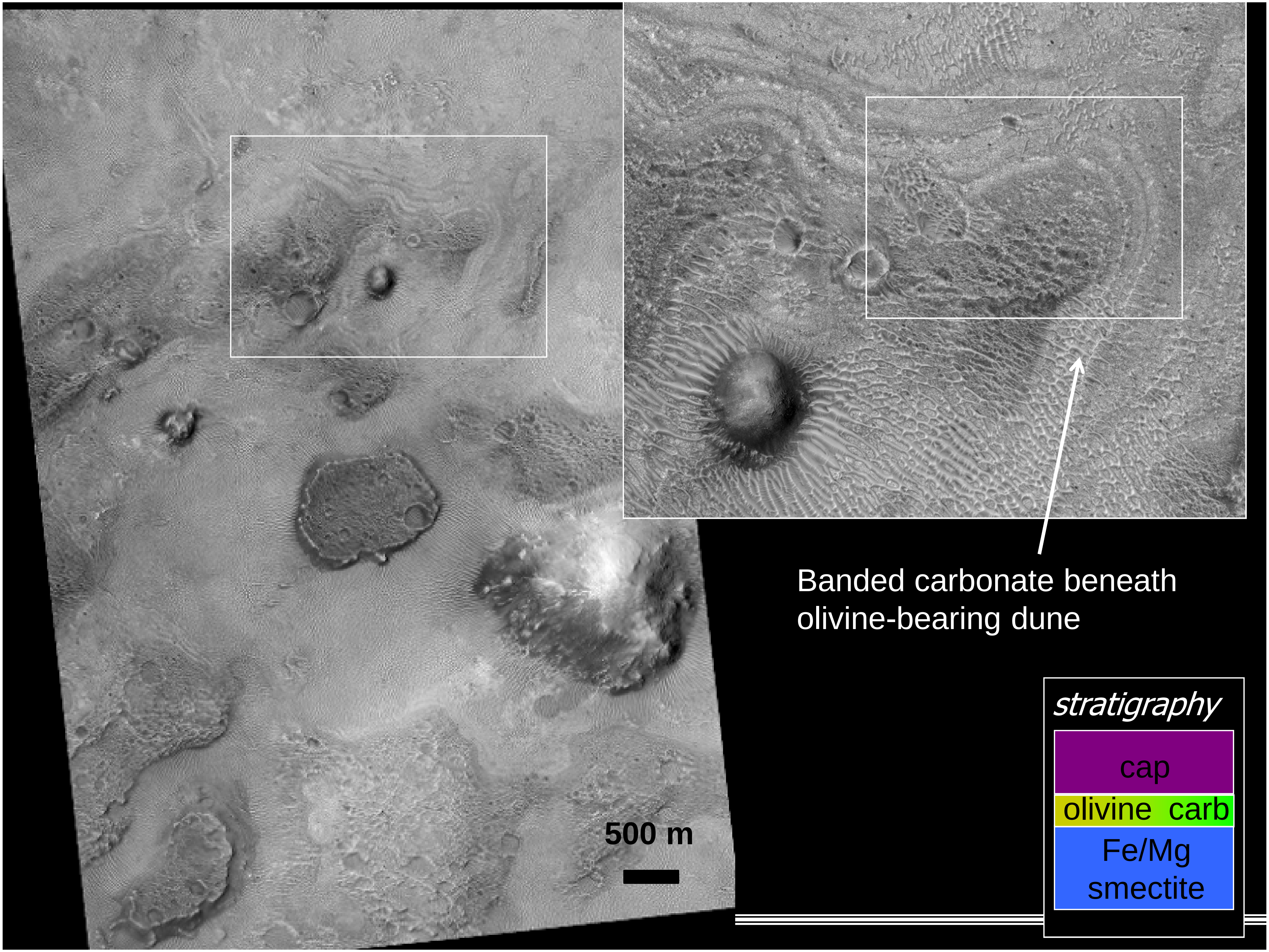

stratigraphy
cap
olivine carb
Fe/Mg smectite
10 km

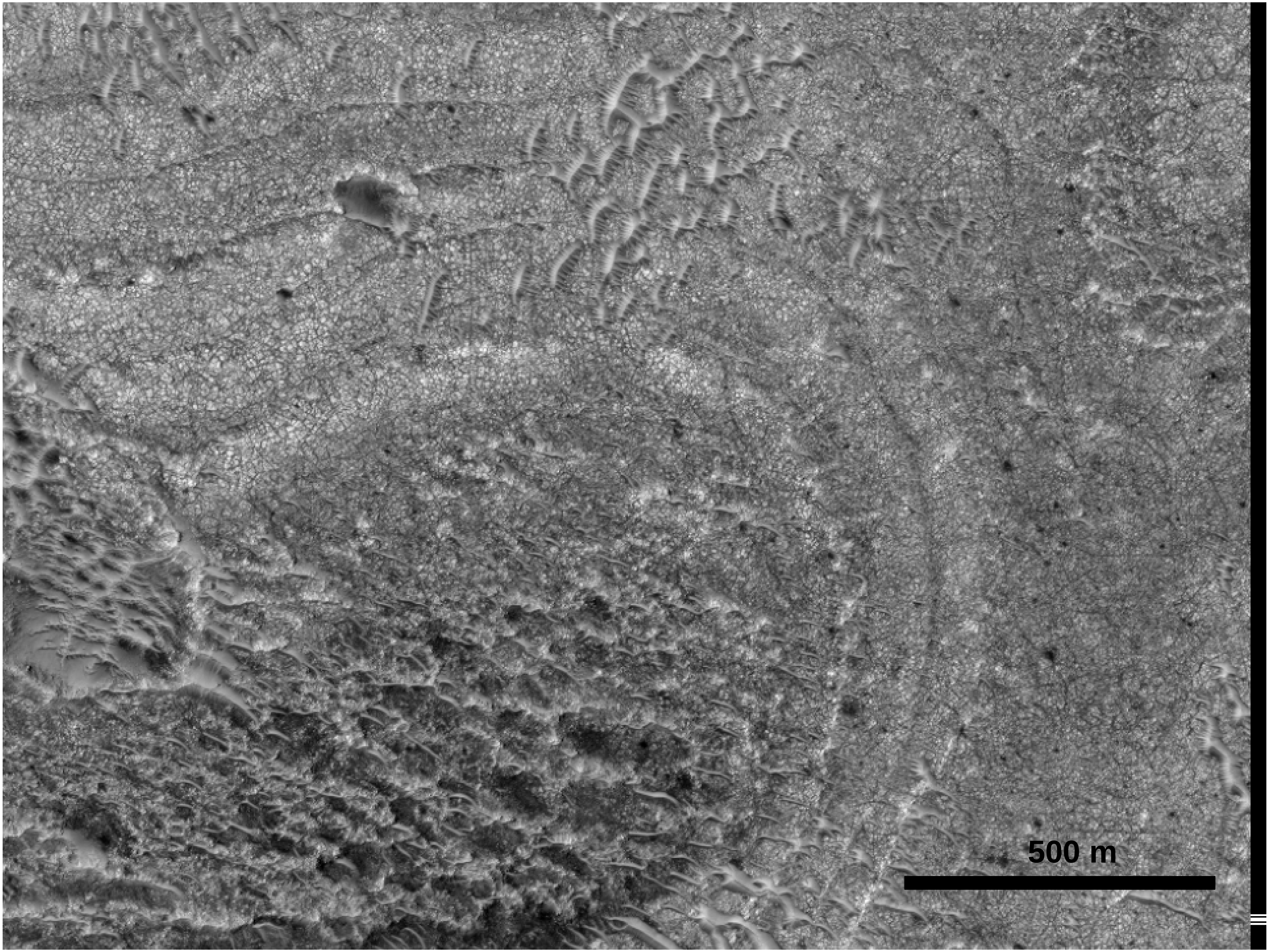
Mineralogy & Exposure

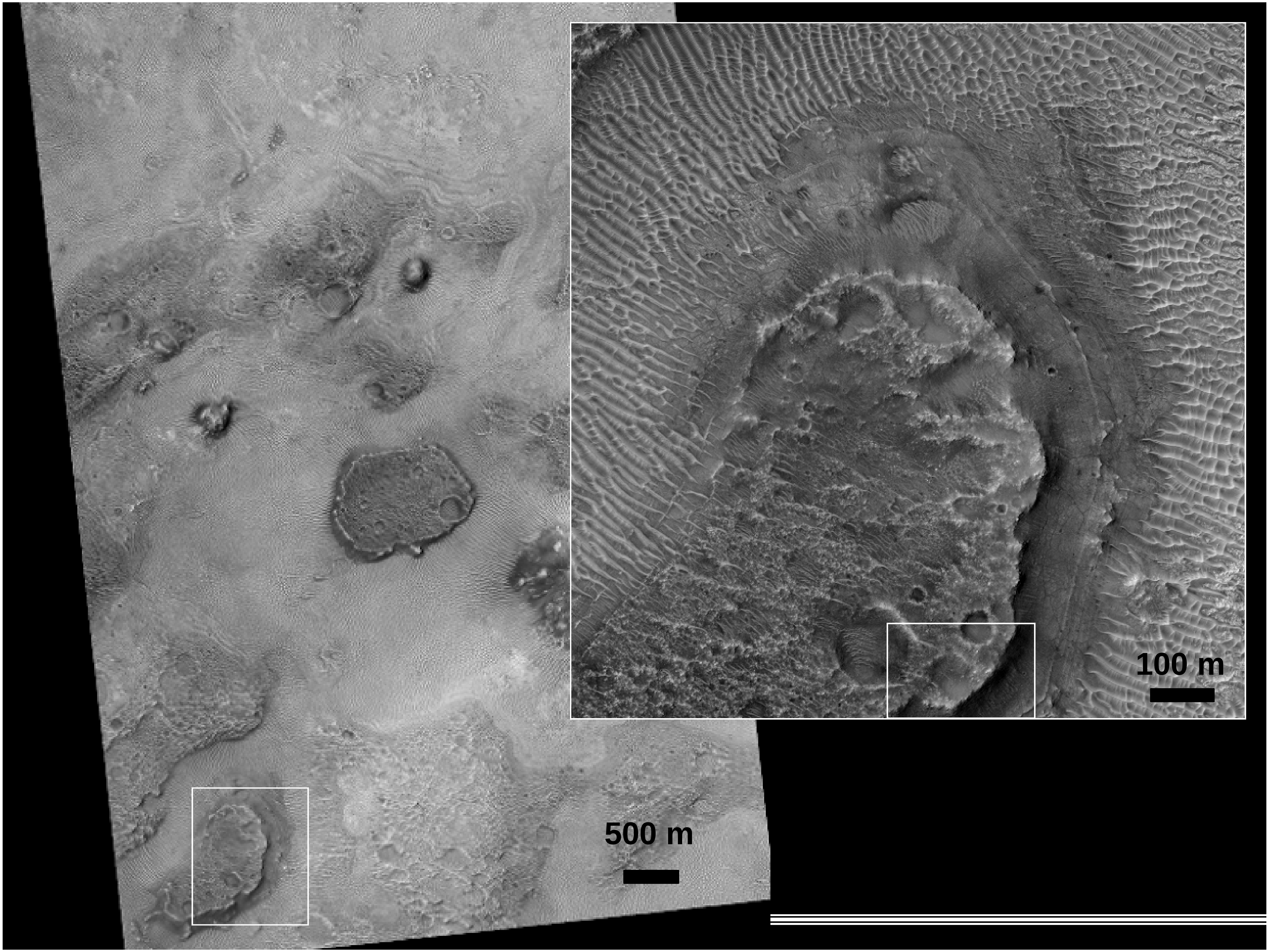


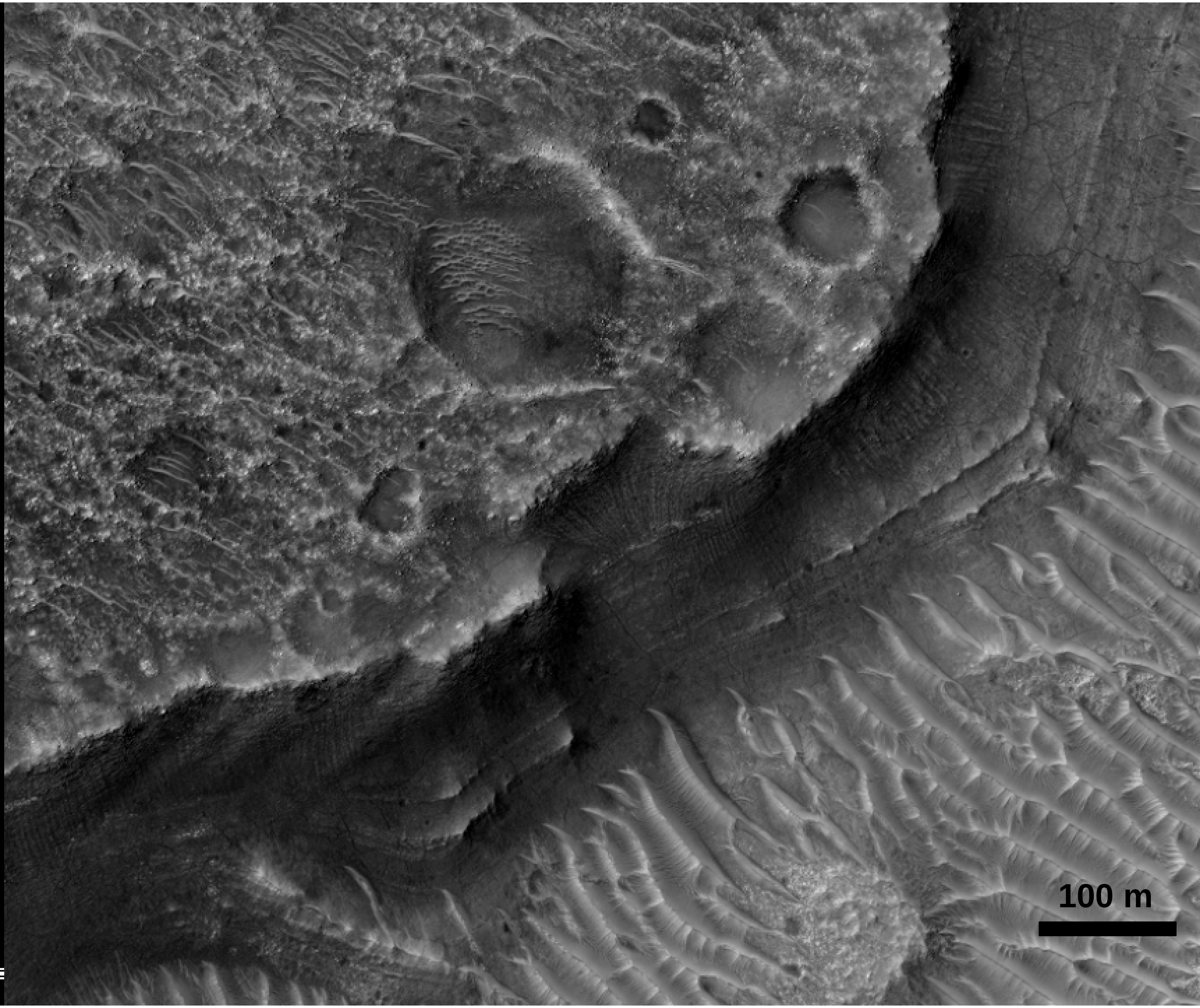


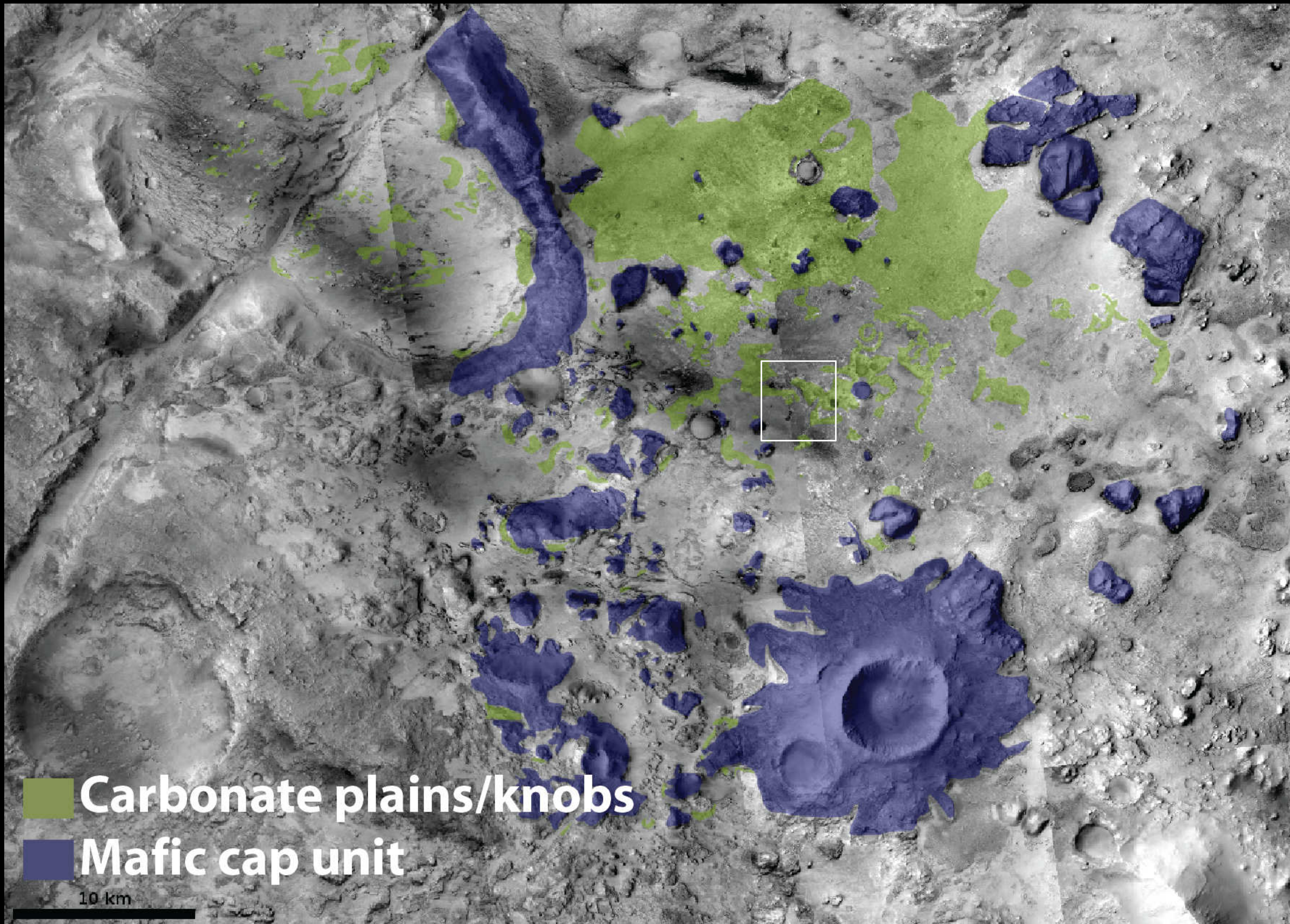

Carbonate plains/knobs
Mafic cap unit
10 km

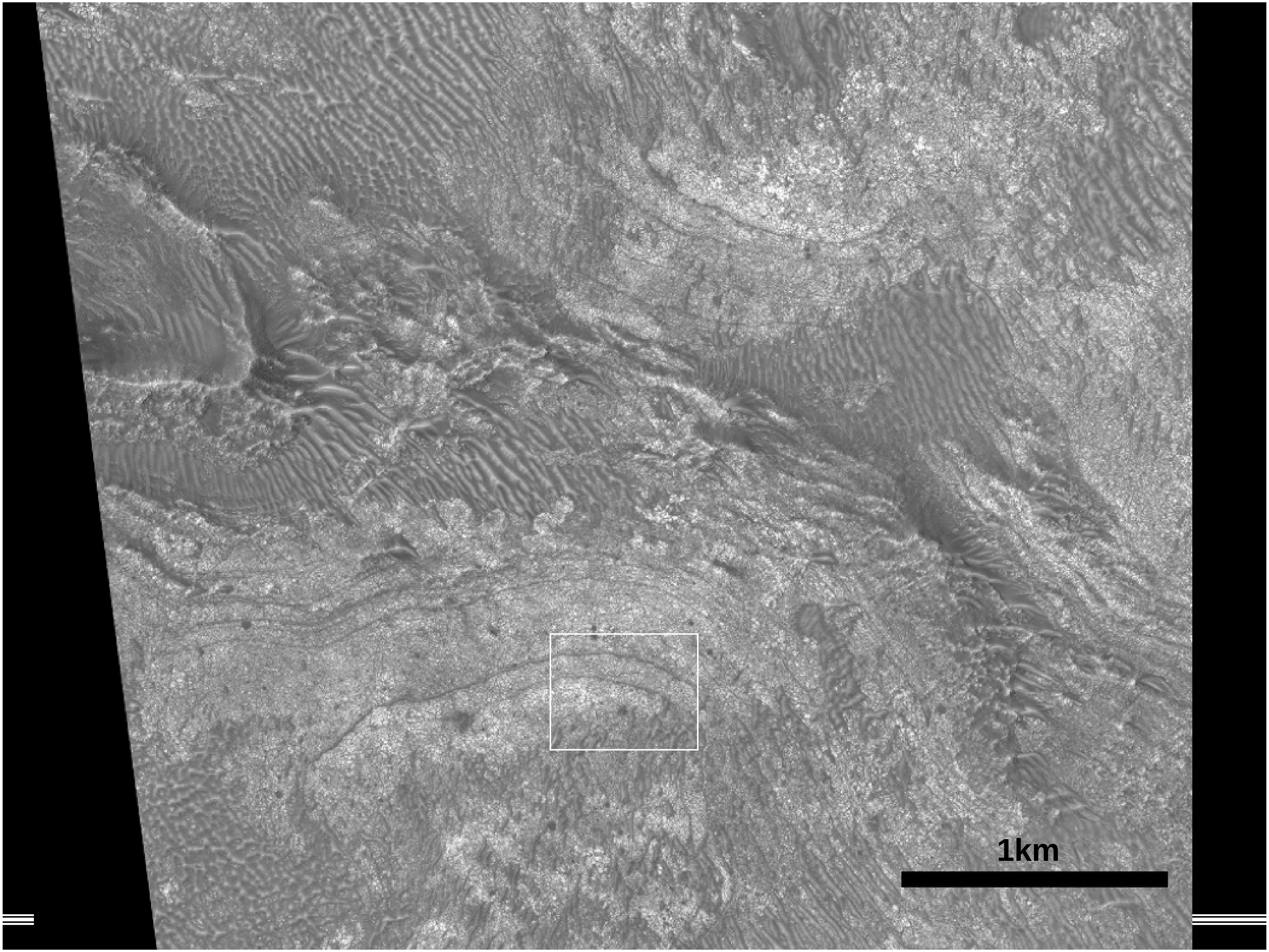

Banded carbonate beneath olivine-bearing dune
500 m
stratigraphy
cap
olivine carb
Fe/Mg smectite

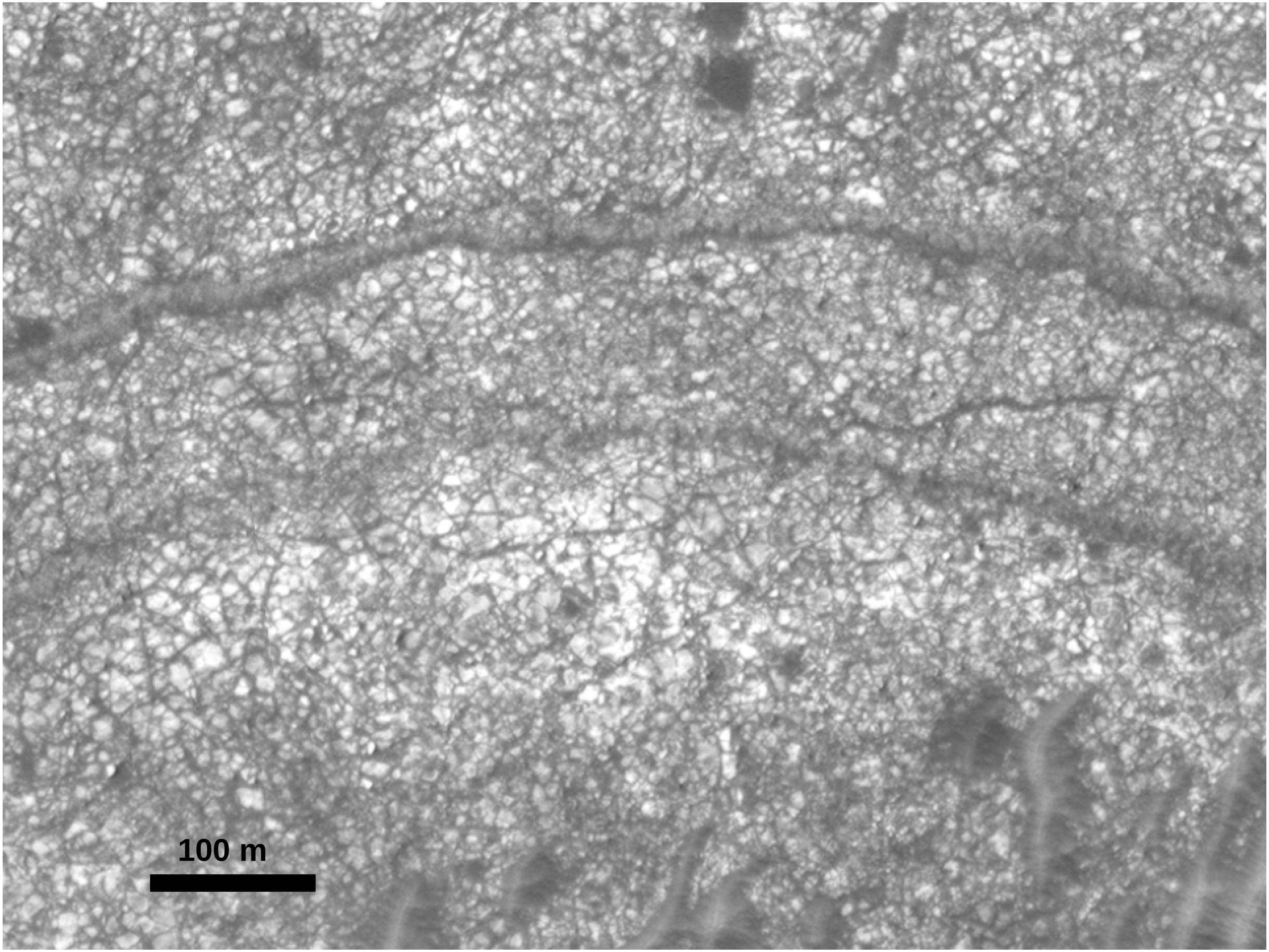

500 m

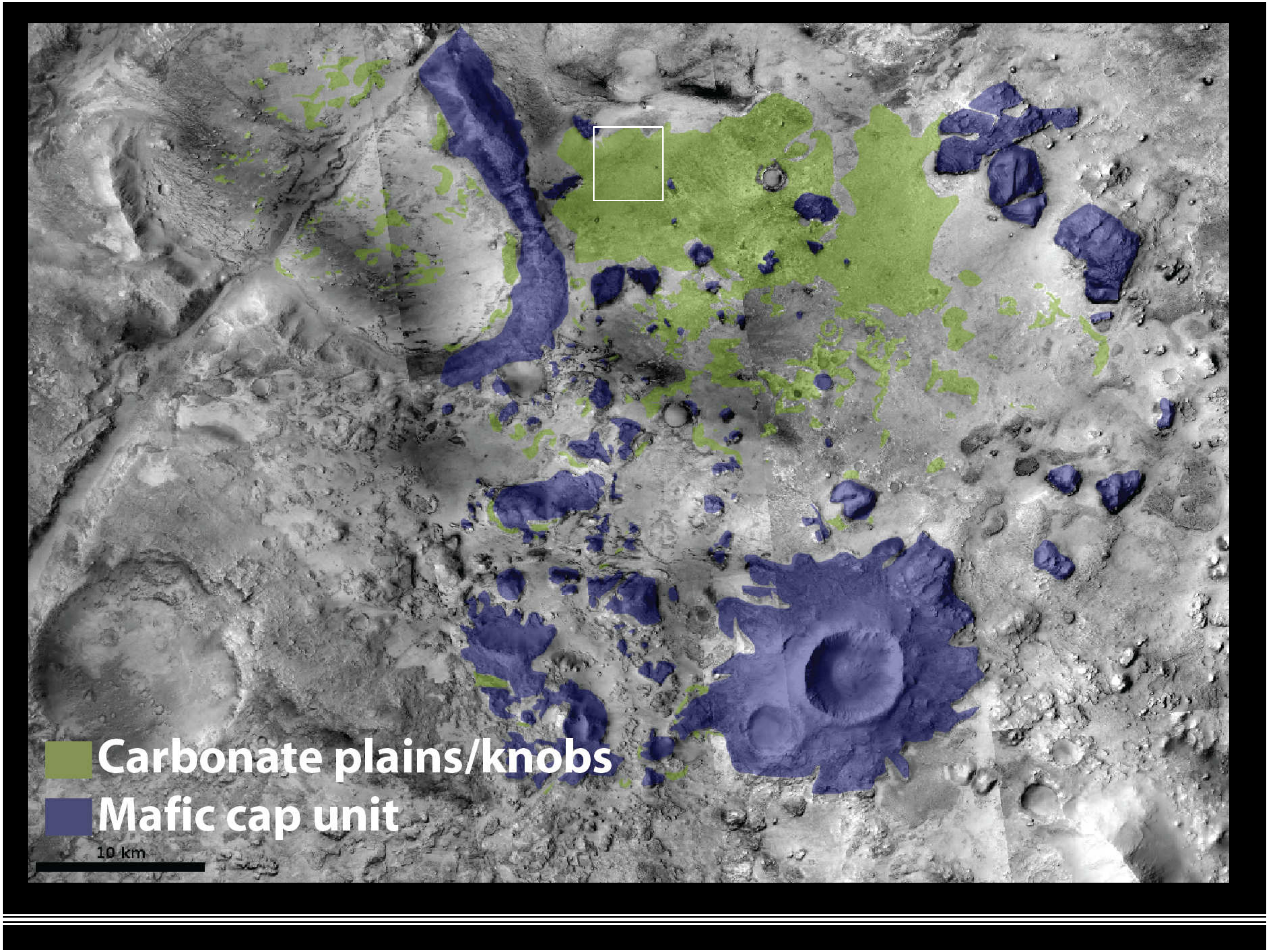

100 m
500 m

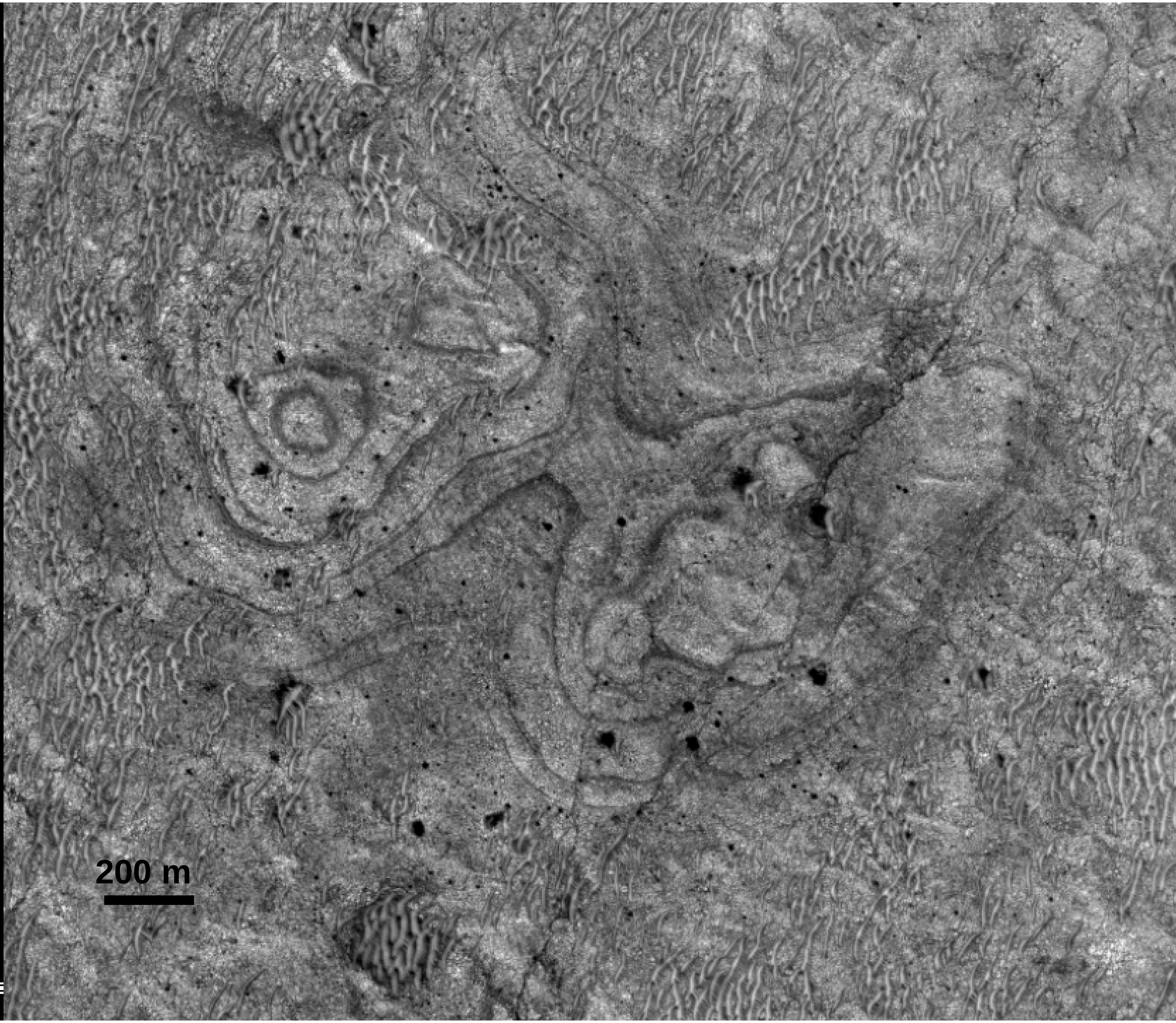

100 m


Carbonate plains/knobs
Mafic cap unit
10 km

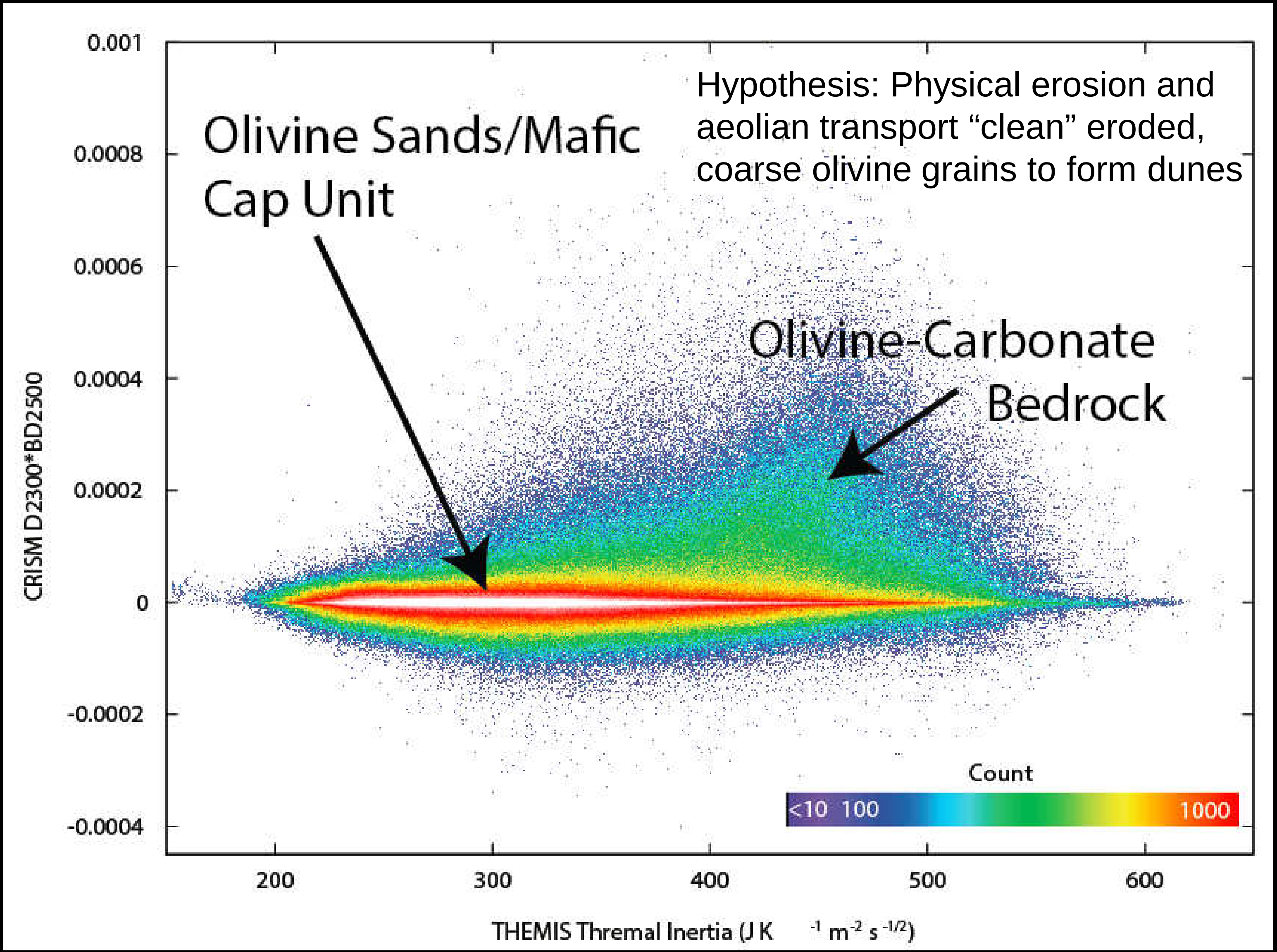

1km


100 m


Carbonate plains/knobs
Mafic cap unit
10 km


200 m

Relationships between key units



Magnesite formation mechanisms (terrestrial)

(Möller, 1989)

Observed elsewhere in the region. Ehlmann et al., 2010, GRL; Ehlmann & Mustard, 2012, GRL

- Hydrothermal fluids
- Serpentinization
- Diagenesis of marine beds

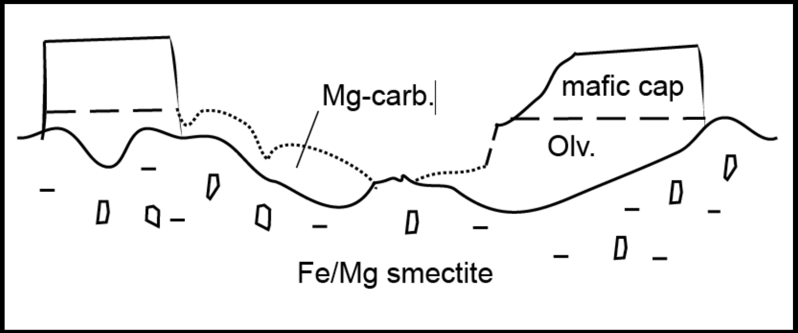
SUBSURFACE

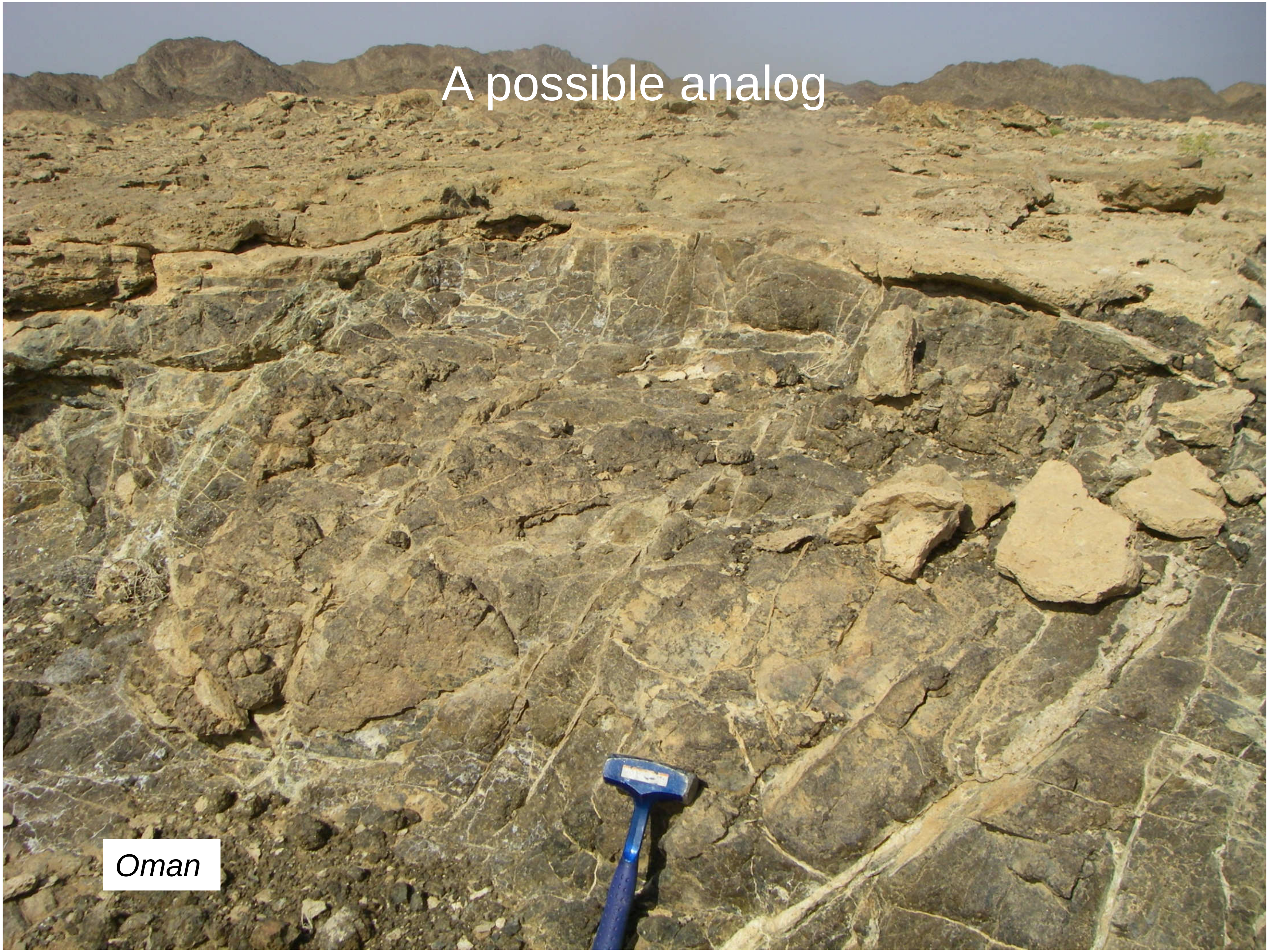
- Weathering of olivine and serpentine rich bodies
- Precipitate in playas fed by ultramafic catchments

SURFACE

For carbonates on Mars,

(1) Olivine-rich rock and (2) its interaction with water seem to be essential




A possible analog
Oman

Tracing the Serpenitinization Process through Carbonate Chemistry

Mg^{+2}-HCO_3^{-1}-Type Waters

Mg-carbonate precipitation

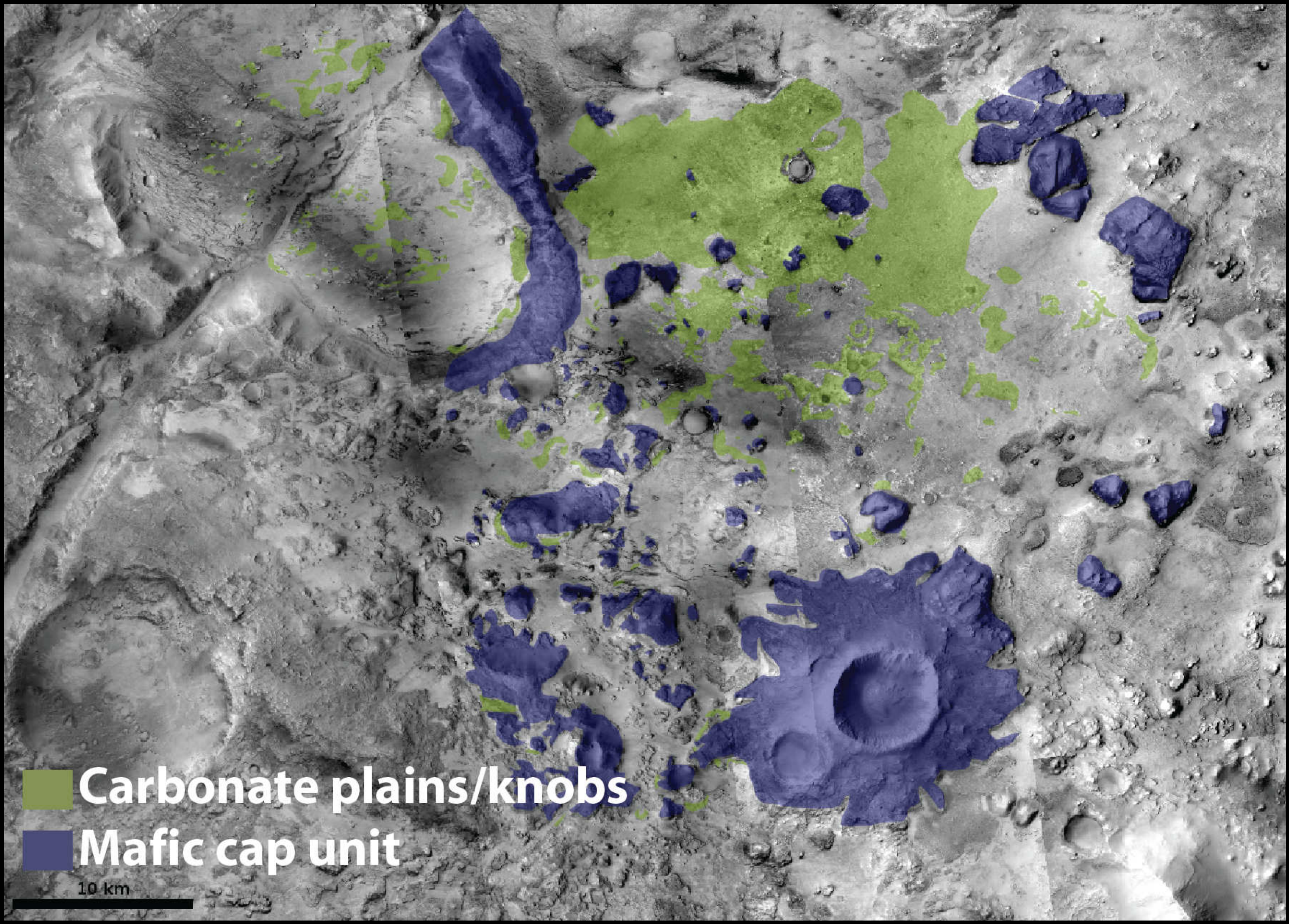
Mg(Fe,Ca)-rich Ultramafic rocks (olivine, pyroxene)

<zone of ongoing serpentinization>

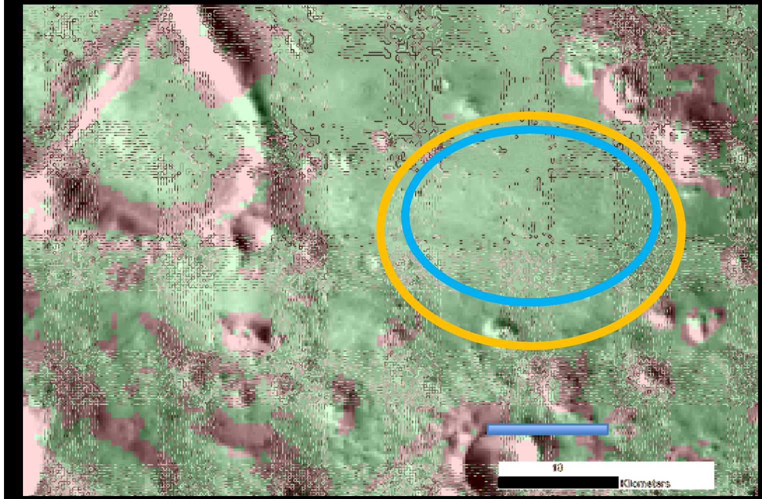
$\rightarrow (Fe,Mg)_3Si_2O_5(OH)_2 + Mg(OH)_2 + H_2$

Ca^{+2}-OH^{-1}-Type Waters

Land-On Carbonate



Preliminary Landing Site Safety



Slope map at 1000 m baseline from MOLA

25km x 20km 18km x 14km

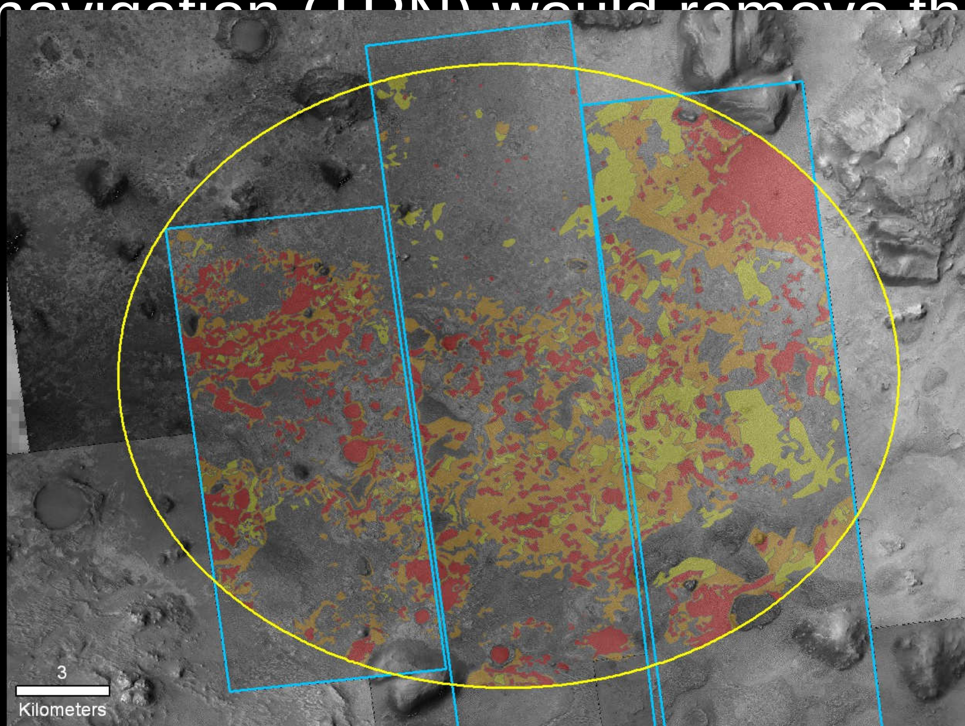
Criteria	Requirement	Actual
Elevation	< +0.5 km	**-1.5 km**
Latitude	±30°	**21.7°**
Relief	<100 m on 1km-1,000 m baselines	✔
Slopes	<25°-30° on 2-5 m baselines	needs investigation
Rocks	~7% rock abundance	appears clear; needs further investigation.
Radar Reflectivity	-20 to +15 dB at Ka band	✔
Thermal Inertia/ Albedo	>100 J $m^{-2}s^{-0.5}K^{-1}$ <0.25	**>230 $m^{-2}s^{-0.5}K^{-1}$ <0.19**

Landing Site Safety: Dunes

Testing the MSL mobility system
Durmont Dunes, CA, Summer ‘12

Landing Site Safety: Dunes

- Large-ellipse (25 km x 20 km at time of downselect) meant MSL landing in the dunes was an unacceptable risk
- Reduced ellipse size, range-trigger, or terrain-relative navigation (TRN) would remove this risk



red=<u>traversability risk</u> due to large dune

See Golombek presentation yesterday

Nili Fossae Carbonate Plains: A Summary

- Immediate Access to Land-On Primary Science
  - Extensive aqueous alteration to form carbonate
    - Testing the relative importance of sedimentation, weathering, and hydrothermal processes for early aqueous environments
    - No later overprinting by an “acid bath”
    - How much carbonate? Stored by what process? Important questions for understanding the global reservoir
  - High-Mg mafic/ultramafic rocks
    - preserves a record of early igneous processes (komatiitic-type melts) or a record of impact processes and mantle-derived cumulates
    - mafic/ultramafic rocks Materials for answering important questions about the nature of the Mars mantle and history of volcanism
- Diverse, fundamental questions about ancient Mars are accessible here, providing decades of work on returned samples